AN EVALUATION OF THE PHASE-OUT MANAGEMENT SYSTEM OF AN OZONE DEPLETING SUBSTANCE HCFC-22 AND ITS ENVIRONMENTAL AND SOCIOECONOMIC IMPLICATIONS IN BOTSWANA

by

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I declare that the above thesis is my own work and that all the sources that I have used or quoted have been indicated and acknowledged by means of complete references.

I further declare that I submitted the thesis to originality checking software and that it falls within the accepted requirements for originality.

I further declare that I have not previously submitted this work, or part of it, for examination at UNISA for another qualification or at any other higher education institution.

SIGNATURE DATE

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ABSTRACT

Climate change and ozone depletion are topical challenges the world over and are both attributed mainly to human activities, particularly emissions of ozone depleting substances (ODSs). One such substance is chlorodifluoromethane (HCFC-22), a cheap, widely used refrigerant with a high global warming potential of 1780. Botswana is a signatory to the Montreal Protocol (MP), which guides international efforts to phase-out HCFC-22 and requires signatories to develop and implement a country-level Hydrochlorofluorocarbon Phase-out Management Plan (HPMP). This study, which used a mixed methods approach, was conducted to evaluate the phase-out of HCFC-22 management strategies and their environmental and socioeconomic implications in Botswana. A census of nine HCFC-22 importing companies was conducted and probability sampling proportional to size was used to select a sample of 159 respondents from the Department of Meteorological Services, HCFC-22 importers, customs officers from 20 purposively selected Botswana entry ports and HCFC-22 consumers from the importing companies. Category-specific respondent questionnaires and interview guides, site visits and assessment of records were used to gather data. Of particular interest were the annual HCFC-22 importation figures for each company, the Botswana Unified Revenue Services and the National Ozone Unit, as well as the level of compliance of the companies' HCFC-22 phase-out management practices with relevant national regulations, the Botswana HPMP and the MP resolutions.

Botswana's HCFC-22 importers were found to be moderately to highly compliant to non-regulatory elements rather than regulatory elements. Overall, HCFC-22 consumption decreased from the baseline to 10.5% for the first stage (2013-2015), which was slightly more than the 10% reduction expected. A steady decrease in HCFC-22 consumption was noted towards the 35% target for 2020, largely due to awareness-raising initiatives directed at the surveyed stakeholders. Absolute HCFC-22 consumption dropped by approximately 510400 kgs from 2011-2017 or 28072 ozone depleting potential saved. On the downside, gaps were identified in the industry-wide quota-system, data reporting, prevention of illegal ODS trade, service technician training, user knowledge of alternatives and disposal of ODS equipment. The study recommends the use of a planning, policy formulation and implementation framework that integrates and balances three fundamentals, namely, stakeholder involvement, the process and the plan enablers.

Keywords: Botswana, phase-out, HCFC-22, Hydrochlorofluorocarbon Phase-out Management Plan, Integrated National Tri-Component HCFC-22 Phase-Out, Ozone, ozone depleting substance, Montreal Protocol, climate change, stakeholders, greenhouse gases

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List of acronyms

AGAGE	Advanced Global Atmospheric Gases Experiment
AID	Agency for International Development
ANOVA	Analysis of variance
APCTT	Asian and Pacific Centre for Transfer of Technology
BCM	Bromochloromethane
BOBS	Botswana Bureau of Standards
BOPA	Botswana Press Agency
Br	Bromine
BRACA	Botswana Refrigeration and Air Conditioning Association
BURS	Botswana Unified Revenue Services
CCl_4	Carbon tetrachloride
CCMs	Chemistry Climate Model
CDOM	Coloured dissolved organic matter
CEEW	Council on Energy, Environment and Water
CFC	Chlorofluorocarbon
CH_2Cl_2	Dichloromethane
CH_3CCl_3	Methyl chloroform
CH_4	Methane
Cl	Chlorine
CMM	Cutaneous malignant melanoma
CO_2	Carbon dioxide
CPT	Cape Point Observatory
CSO	Central Statistics Office
DEA	Department of Environmental Affairs
DIW	Department of Industrial Works
DMS	Department of Meteorological Services
DNA	Deoxyribonucleic acid
DU	Dobson units
EC	European Community
ECC	Electrochemical concentration cell
EEAP	Environmental Effects Assessment Panel
EER	Energy efficiency ratio

EFTC	European Fluorocarbons Technical Committee
EIA	Environmental Investigation Agency
ENSO	El Niño–Southern Oscillation
EPA	Environment Protection Authority
ESCAP	Economic and Social Commission for Asia and the Pacific
GEF	Global Environment Facility
GHG	Greenhouse gas
GMST	Global mean surface temperature
GoB	Government of Botswana
GRSA	Government of the Republic South Africa
GTC	Gaborone Technical College
GWP	Global warming potential
HC	Hydrocarbons
HCFC	Hydrochlorofluorocarbon
HCFC-22	Monochlorodifluoromethane
HCI	Chloride
HEFAT	Hostile Environment and First Aid Training
HF	Hydrogen fluoride
HFCs	Hydrofluorocarbons
HFO-1234yf	Hydrofluoroolefin
HPMP	Hydrochlorofluorocarbon phase-out management plan
HPPMP	Hydrochlorofluorocarbon production phase-out management plan
HSD	Honestly significant difference
HVACR	Air conditioning and refrigeration
INTHPO	Integrated National Tri-component HCFC-22 Phase-Out
IPCC-	Intergovernmental Panel on Climate Change
IT	Information technology
ITAC	International Trade Administration Commission
ITCZ	Inter-Tropical Convergence Zone
KP	Kyoto Protocol
MDG	Millennium Development Goals
MeBr	Methyl bromide
MLF	Multilateral Fund

MoP	Meeting of Parties
MP	Montreal Protocol
NAO	North Atlantic Oscillation
NASA	National Aeronautics and Space Administration
NO	Nitric oxide
NO_2	Nitrogen dioxide
N_2O	Nitrous oxide
NOAA	National Oceanic and Atmospheric Administration
NOO	National Ozone Office
NOU	National Ozone Unit
O	Oxygen
O_3	Ozone
ODP	Ozone depleting potential
ODS	Ozone depleting substance
OH	Hydroxyl radical
PANs	Peroxyacyl nitrates
PPS	Probability proportional to size
PDO	Pacific Decadal Oscillation
PFCs	Perfluorocarbons
PSC	Project Steering Committee
PSC	Polar stratospheric clouds
RAC	Refrigeration and air conditioning
RACA	Refrigeration and Air Conditioning Africa
RACSS	Rochester Area Council for the Social Studies
RR	Recovery and recycling
RRRP	Refrigerant Recovery Recycling Project
SA	South Africa
SARACCA	South Africa Refrigeration and Air Conditioning Contractors Association
SARDC	Southern African Research and Documentation Centre
SARS	South Africa Revenue Service
SASO	Saudi Standard Organisation
SCA	Saudi Customs Authority
SH	Southern hemisphere

SME	Small to medium enterprises
SPARC	Stratosphere-Troposphere Processes And their Role in Climate
SF_6	Hexafluoride
SWSA	Southwestern South Africa
TPMP	Terminal Phase-out Management Plan
TRDJSM	Top Research Group Journal of Science and Management
UK	United Kingdom
USA	United States of America
UN	United Nations
UNDP	United Nations Development Program
UNEP	United Nations Environment Program
UNFCCC	United Nations Framework Convention on Climate Change
UNIDO	United Nations Industrial Development Organization
USSR	Soviet Socialist Republics
UV	Ultra violet
UV-B	Ultra violet B
VAT	Value added tax
VC	Vienna Convention
VCPOL	Vienna Convention for the Protection of the Ozone Layer
VOCs	Volatile Organic Compounds
WHO	World Health Organization
WMO	World Meteorological Organization
ZIMRA	Zimbabwe Revenue Authority

CHAPTER 1

INTRODUCTION AND STUDY BACKGROUND

1.1 Background to the study

At the centre of the world's debate on environmental problems in the last three decades have been the twin issues of climate change and ozone layer depletion (Sunstein, 2007, Ogunniran, 2018). Human civalisation through innovation in technology in a bid to improve life has resulted in the use of substances that result in ozone depletion and climate change (Mosha, 2011; Ghanbari, 2012). Wan *et al.* (2011) concluded that accelerated economic growth and technical development throughout the world during the last century have come at the cost of severe environmental insecurities. Both issues are global in scale, emanate from diverse nations, and hence, require multilateral consensus on their solution (Jianping *et al.,* 2013; Morin *et al*., 2020). In addition, both problems, while imputable to current generations generally and wealthy nations in particular, largely affect poorer continents, especially Africa and Asia (Ogunniran, 2018).

The consumption and release of ozone depleting substances (ODS) into the atmosphere are the main cause of ozone depletion, which leads to climate change and global warming (United Nations Environment Program (UNEP), 2014a). Pisso *et al.* (2010) define ODS as anthropogenic gases that destroy the stratospheric ozone once they reach the ozone layer. The gases are characterised as either short-lived or long-lived, depending on their atmospheric lifetime. The use of refrigerants and cooling products, which are the main sources of ODS, is increasing at an alarming rate on a global level, especially in Africa, Asia and South America in various sectors like food storage, the construction and the oil industries, as well as car and household air conditioning (A-Gas South Africa, 2010; Benhadid-Dib and Benzaoui, 2012). Transformational scientific research on the ozone layer started in 1975, but objective data and measurements were only recorded in the 1980s subsequent to the realisation that the ozone level recorded prior to 1975 had depleted by more than 50% (Matsunaga, 2002; The Global Environment Facility (GEF), 2010). This ozone depletion was caused mainly by either direct or indirect release of ODS in the form of refrigerants, pesticides and substances used for fire-fighting. These subsequently resulted in the harmful ultraviolet-B (UV-B) radiation penetrating the atmosphere, causing skin cancers, disease and vegetation damage, among other effects (Anwar *et al*., 2016; Andrady *et al.*, 2017; Bais *et al.*, 2018).

On a positive note, significant strides have been made towards eradicating the manufacture and usage of ODS, with the Kyoto Protocol (KP) also making some contributions towards the containment of greenhouse gas (GHG) emissions (Sunstein, 2007; Sandler, 2017). The Montreal Protocol (MP) and KP environmental summits are considered to be the main frameworks for the regulation and prohibition of ODS used in refrigeration, air cooling and fire-fighting equipment (Green, 2009; Ogunniran, 2018). These ODS have greenhouse effects and they affect the ozone layer and consequently cause extreme climate changes through physical and chemical processes (UNEP, 2012a; Hossaini *et al.,* 2017). According to the United Nations Development Program (UNDP, 2014) and the UNEP (2016a), the MP is globally regarded as the most ground-breaking successful environmental protection convention at United Nations level.

The MP is a legally binding universal treaty on the prohibition, consumption and production of ODS and has been ratified by 197 United Nations member countries, with mandatory timelines committed and agreed to by all signatories for phasing out the refrigerant chlorodifluoromethane (HCFC-22) (A-Gas South Africa, 2010; Sandler, 2017). The MP summit is viewed as the best United Nations ratification summit with unanimous agreement on the complete phasing out of CFCs before the year 2000 and the adoption of the transitional less harmful ODS, HCFC-22, and its subsequent progressive complete phase out by the year 2040, with defined and mandatory HCFC-22 phase-out milestones. Botswana became a signatory to the MP and the Vienna Convention for the protection of the ozone layer on the 2nd of March 1992 and went on to ratify all the amendments to the MP (UNEP, 2011a; Botswana Meteorological Services, 2014: UNEP, 2018a). The Global Environment Facility (GEF) (2010) established in 1991 pursuant to the MP is recognised as a project funder for the developing countries through grants, technical support and approved technology transfer; and provided US$210 million in developing countries for the phasing out of ODS in 2010. According to the UNDP (2014), the Multilateral Fund (MLF) enabled developing countries to reduce chlorofluorocarbons (CFCs) by about 50% (1991-1992), and the reduction in 1995 of hydrochlorofluorocarbon (HCFC) in refrigeration and chemical industries. By the end of the year 2014, more than 120 developing countries, including Botswana, were assisted through grants and technical assistance to eliminate 67 870 tonnes of ODS, simultaneously setting a target of 35% HCFC-22 reduction by the year 2020 (UNDP, 2014; Ntakhwana, 2018).

According to the Swedish Environmental Protection Agency (2010), the MP classified all developing nations under Article 5 and it was mandated under the agreement to halt consumption and production of HCFC in 2013. This was followed by a decrease of 10% by the year 2015, and a targeted further reduction of 35% by the year 2020, eventually leading to a 100% phase out by the year 2040, with only 2.5% of HCFC reserved for servicing purposes between the years 2030 and 2040 (Velders *et al.,* 2007; UNEP, 2012a; Koszegvary, 2013; UNEP, 2016b).

Further to the ratification of the management plan for the ODS phase-out, the MP introduced three hydrocarbons as alternatives to HCFC-22 for household and small commercial refrigeration, including approval of the use of carbon dioxide and hydrofluoroolefin (HFO-1234yf) as car refrigerants (Minor and Spatz, 2008; Environmental Protection Agency (EPA), 2010). Compounds that are composed of only chlorine, fluorine and carbon are called CFCs and are extensively used in the air cooling and refrigeration industries. Scientific research has shown that the ozone depletion was also a result of the release of chlorine from CFCs into the stratosphere (Solomon *et al.,* 2014; Hossaini *et al.,* 2017; Ball *et al.,* 2018). While the introduction of CFCs and later HCFCs solved the important safety problems, the environmental risks were not considered until the mid-1970s (Ramayia, 2012). Developed countries are currently at an advanced phase-out stage compared to developing countries which are still using HCFCs as a major refrigerant (Velders *et al.,* 2012). As from 2016 to 2019, Australia has limited HCFC annual imports of about 45 tonnes of HCFC-22 (Australia Government, 2019). Botswana is one of the heaviest users of HCFCs with annual import of 200 metric tonnes (UNEP, 2011a; UNEP, 2015a; UNIDO, 2015).

The South African Department of Economic and Social Affairs (2013) noted that South Africa's consumption of ODS, namely, hydrofluorocarbon (HFC), bromochloromethane (BCM) and methyl bromide (MeBr), rose between the years 2004 and 2009. HCFCs constituted the highest consumption of 81.4% (25 759 tons), followed by HFCs with 10.9% (3 439 tons), methyl bromide (MeBr) with 2.4% (747 tons) and bromochloromethane (BCM) with 2% (624 tons). Most of these are imported by South African companies from Germany, China, Israel, India and the Netherlands for subsequent export to Botswana, Malawi, Mozambique, Zimbabwe and Zambia (South Africa Department of Economic and Social Affairs, 2013).

Botswana is a major importer of HCFC-22 from South Africa (SA). HCFC-22 is the least expensive refrigerant used in Botswana (UNEP, 2015a; Ntakhwana, 2018). Additionally, since

Botswana does not produce HCFCs, all HCFC-based refrigeration equipment used is imported mainly from SA. HCFC-22 represents 99.95% of utilisation and is overwhelmingly used in adjusting refrigeration and cooling hardware (UNEP, 2018b).

According to the UNEP report (2015a), the official Botswana implementation agent of the HCFC phase-out management plan (HPMP), which started in 1994 (Phase 1), continued in 2012 (Phase IV), and then 2016 (Phase V), is the UNEP. This led to grant disbursements of US$324 719 (for Phase 1-IV) and US$100 061 for Phase V with approval of the HCFC management plan taking place in 2015. The summary of grants and activities approved by the UNEP executive (UNEP, 2015a) for Botswana included institutional strengthening (US$480 000), investment projects (US$324 719) and project decommissioning, training and support (US$620 970).

The UNEP Secretariat (UNEP, 2011a) sought further clarification from Botswana and proposed the establishment of an HCFC-22 licensing system through the establishment of an ODS import and export licensing system as the ratifications of MP decision XXII/19 of the 22nd Montreal meeting, which proposed aggregate reduction of HCFC-22 consumption to 11.01 ozone depleting potential (ODP) tonnes, with a baseline of 11.40 ODP tonnes. The executive committee of the secretariat (UNEP, 2015a) further recommended that in Botswana, a subsequent HCFC-22 reduction be effected for the period 2016-2020 to meet the 35% consumption reduction by the year 2020.

South Africa Environmental Affairs (2010) recorded that Botswana imported 32.6 tonnes of HCFCs from South Africa in 2009. This was recorded as the second highest in Southern Africa with Mozambique being the highest, importing 40.8 tonnes of HCFCs. In the case of Botswana, the Department of Meteorological Services established a National Ozone Unit (NOU) which is in charge of coordinating ozone activities (UNEP, 2016b; 2018c). The NOU took steps to phase-out HCFC-22 or R-22 in favour of hydrofluorocarbons (HFCs). Unfortunately, most HFCs are powerful GHGs with high potential to cause global warming and are incorporated in the KP (Fang *et al.,* 2016). The management systems drawn up in compliance with the Montreal summit ratifications on the complete phasing out of HCFC-22 refrigerant from importation, consumption and disposal have prompted the researcher to seek empirically based recommendations for these in the specific context of Botswana. Parties to the Montreal Agreement in the year 2007 accelerated the HCFC-22 phase-out management plans through additional multilateral financing and also the simultaneous adoption of least impact ODS (Barton, 2014).

1.2 Research problem

A plethora of scientific studies into ODS has revealed that ozone is a naturally occurring rare gas stretching from about 10 to 50 kilometres above the surface of the earth and is an effective shield for the planet earth against the destructive UV radiation from the sun (World Meteorological Organization (WMO), 2008; EPA, 2010; UNEP, 2014a; 2014b; Haar, 2016; Ogunniran, 2018). The harmful rays destroy human and plant immune systems, resulting in death (Krzyscin, 2014). The continuing relatively limited debate on ODS in the refrigeration and cooling industries has constrained administrative intervention in both developed and developing nations including Botswana (Meyer, 2006; Goitsemang, 2016). CFCs and HCFCs are fundamental gases that are used in the production of refrigeration, air cooling systems, chemical solvents, the food industry, health respiratory inhalers and fire fighting equipment. Scientific research has shown CFCs to be the most harmful ODS, leading to their successful progressive phase-out in the late 1990s through the MP summit of the United Nations (Ashraf, 2008; Ravishankara *et al.,* 2009; Wang *et al.,* 2016; Labacher (2017).

This study aimed at evaluating the phase-out management systems of HCFC-22 and the environmental implications for Botswana. HCFC-22, being the least expensive ODS in South Africa and Botswana, has been widely adopted and consumed, especially in the refrigeration and air cooling industries (UNEP, 2015a; 2016c). However, because of its ODP, HCFC-22 has been restricted in large part in Non-Article 5 (developed) countries and a limited import will be executed in Botswana until an aggregate boycott comes into being in 2030 (Botswana Meteorological Services, 2014; UNEP, 2015b). The effects of a depleted ozone layer, global warming and climate change have caused serious human and environmental problems in recent years (UNEP, 2014b; Kuttippurath *et al.,* 2018; Ogunniran, 2018). SA, which is both an importer of HCFC-22 and an exporter to other countries, including Botswana, is at an advanced stage of implementing the Montreal summit ratifications of the HCFC-22 phase-out through legislation (UNEP, 2016c). Botswana, also an MP signatory and HCFC-22 importer from SA, is negatively affected strategically and operationally and also in terms of Montreal summit compliance (UNEP, 2015a). Consequently, the management of the importation, consumption, disposal and phase-out of HCFC-22 is a major problem the government of Botswana is facing. Currently, most of the Montreal treaty parties have made successful significant strides in the

HCFC-22 phase-out plans, since they are more concerned with compliance, as opposed to effectiveness, which encompasses the overall evaluation of the successful environmental goals (Norman, 2011). Evaluating the effectiveness of the Montreal treaty is effected by observing the outcomes of commitment met and the impact (Norman, 2011). It is against this background that the researcher was prompted to identify these research gaps and evaluate Botswana's HCFC-22 phase-out management strategy and make effective recommendations.

1.3 **Rationale and motivation**

Botswana exhibits desert climatic conditions, making it imperative to import refrigeration and air-cooling substances and equipment (Tlou Energy, 2012; Chaney, 2016). Since Botswana is an MP signatory and also predominantly a net importer of HCFC-22 substances and equipment, it is under intense pressure for compliance.

The commercial nature and low pricing of HCFC-22, as compared to other ODS, has caused many countries today to have a higher demand for HCFC-22 than in 1998, when the phase-out of the refrigerants started (UNEP, 2014c). Though a number of alternative refrigerants causing no ozone depletion are available, the equipment using HCFC-22 is still a best seller (UNEP, 2011a; Dreepaul, 2017*;* UNEP, 2019a). The worldwide emissions of HCFC-22 refrigerant (360.6 ± 58.1 Gg yr^{-1}) (Simmonds *et al*., 2017) can seriously damage and alter the ozone layer in a way that is likely to have a detrimental impact on human health and on the environment.

Temperature control is also a necessity in many buildings, including hospitals, laboratories, mortuaries, the cold chain for food products and computer equipment (Meyer, 2006). Consequently, all stakeholders must be involved in HCFC-22 phase-out programmes for ozone protection. Hence, the subject is taking a central position in the national environmental policies of many countries (UNEP, 2008; Wan *et al.,* 2011; Simmonds *et al.,* 2017). Regrettably, policy makers often fail to base their decisions on empirical evidence emanating from scientific research. It is hoped that the findings of this study will significantly assist government and development partner institutions to carry out evidence-based policy advocacy and public awareness on ozone depletion mitigation. The research output will provide information to policy makers to enable them to formulate fitting legislation connected to the phase-out of ODS/HCFC-22 and ozone protection. Despite technical and grant support for the phasing out of HCFC-22, developing countries are alleged to have made little progress in implementing the HCFC phase-out management strategies (UNEP, 2014c). The evidence-based recommendations emerging from this study will guide HCFC-22 phase-out and anti-ozone depletion efforts. Furthermore, the recommendations may also provide input to the identification and prediction of the likely future changes, efforts to formulate policy, programmes and activities that could accelerate the phase-out of HCFC-22 and other ODS. Granted, the geographic scope of the study is limited to a specific part of Botswana; the relevance and usefulness of the results may, however, be extended to other international regions and countries exhibiting similar climatic and socioeconomic characteristics.

The current study can provide baseline information for further studies on effective HCFC-22 phase-out and the curbing of ozone depletion. Broadly, two research gaps have been identified. The first is the fact that no study to evaluate the effectiveness of HCFC-22 phase-out plans in Botswana has been carried out before. The second gap emanates from the fact that in the 15^{th} meeting of the signatories to the MP decision XV/31 and the 65^{th} meeting decision XXV/15, Botswana was found to be lagging behind in the fulfilment of its commitments as a signatory of the MP (UNEP, 2012a; 2015a; 2016b). These gaps have necessitated the execution of this nationally orientated study.

1.4 **Aim of the research**

This research aimed to evaluate the phase-out management system of an ODS, HCFC-22, and its environmental and socioeconomic implications for Botswana. Accordingly, the awareness, effectiveness and impact of Botswana’s HCFC-22 phase-out management strategies, as prescribed by the Montreal Protocol, to which the country is a signatory, were evaluated.

1.5 **Objectives of the research**

The following objectives were formulated for this study:

a. To assess the levels of awareness and product knowledge of service and regulatory stakeholders in the importation and distribution of HCFC-22 in Botswana.

b. To examine the Botswana’s HCFC-22 phase-out management system.

c. To evaluate the level of compliance of Botswana with the Montreal Protocol resolutions on the monitoring, consumption and phasing out of HCFC-22.

d. To evaluate the milestones in the HCFC-22 phase-out trend pursuant to the Montreal Protocol.

e. To examine the economic, social and environmental implications of phasing out HCFC-22.

f. To compare and contrast South Africa’s and Botswana’s HCFC-22 phase-out management strategies and implementation based on the Montreal Protocol resolutions.

g. To provide recommendations for an effective HCFC-22 phase-out strategy.

1.6 **Research questions**

a. What level of awareness and product knowledge do stakeholders in the regulatory, importation and distribution of HCFC-22 in Botswana have?

b. How does Botswana manage the phase-out of HCFC-22?

c. To what extent is Botswana compliant with the Montreal Protocol resolutions on the monitoring, consumption and phasing out of HCFC-22?

d. What milestones have been achieved by Botswana in the phase-out of HCFC-22 pursuant to the Montreal Protocol?

e. What are the social, economic and environmental implications of phasing out HCFC-22?

f. How similar and/or disparate are South Africa’s and Botswana’s HCFC-22 phase-out management strategies and implementation based on the Montreal Protocol resolutions?

g. What recommendations can be provided to ensure an effective HCFC-22 phase-out strategy?

1.7 Limitations of the study

HCFC-22 is the cheapest refrigerant and is commonly used in Botswana. The researcher examined the HCFC-22 phase-out management systems of all the companies in Botswana that are registered to import the ODS. The major limitations of this research are that, owing to the limited study time frame, some respondents did not participate in the final stage of data collection as they were either not there or reluctant to do so. As a result of the failure of respondents to respond in time, the results may not be an accurate reflection of the views of the whole study population.

Notwithstanding the researcher's efforts to obtain data on most of the study variables, it was difficult to compile a comprehensive account of HCFC-22 variability trends over extended periods owing to the unavailability of well-organised data for some HCFC-22 importing companies in Botswana. Some participants were unable to provide adequate data as a result of poor record-keeping systems and it is also not inconceivable that many of the study respondents may have either exaggerated or understated certain facts, especially the quantities of HCFC-22 imported or consumed, to promote a positive image. This would have distorted the results; nevertheless there was nothing much the researcher could do beyond relying on the facts and figures as given. However, besides these limitations, measures were taken to ensure that the study was not heavely affected by the limitations. To overcome the issue of poor record keeping and the accuracy of data by importing companies, data on HCFC-22 imports was also collected from Botswana Unified Revenue Services (BURS) and the National Ozone Unit (NOU). The BURS record all the HCFC-22 imported into Botswana and report to NOU where as all companies report their imports to NOU. The NOU then reconcile the reported imports and report nationally.

1.8 Operational definitions

Article 5 parties: Any developing country whose annual calculated level of consumption of the controlled substances in Annex A is less than 0.3 kilograms per capita on the date of the entry into force of the Protocol.

Chlorodifluoromethane: A hydrochlorofluorocarbon (HCFC), colorless gas known as HCFC-22 or R-22 or $CHClF_2$.

Consumption: production plus imports minus exports of controlled substances.

Montreal Protocol: An international treaty designed to protect the ozone layer by phasing out the production of numerous substances that are responsible for ozone depletion.

Ozone depleting potential: The ability of a controlled substance to destroy the atmospheric ozone based on atmospheric lifetime, stability and reactivity.

Ozone depleting substance: Any chemical substance which destroys the ozone layer and is controlled under the Montreal Protocol.

Ozone depleting substance: Dependent equipment- means products or equipment consisting of ozone depleting substances, including equipment whose continuous functioning relies on the use of ozone depleting substance.

Quota system: A quantitative limit of releasing, for free circulation in a country, of imported controlled substances which shall be subject to limits and allocation by using the licensing system.

1.9 **Study area**

This study focused on the evaluation of the management system for phasing out HCFC-22, an ODS, in Botswana. Botswana is a landlocked country spanning approximately 582 000 square kilometres (km$^{2)}$ in area and is located in Southern Africa (The World Factbook, 2016) to the north of SA. The total boundary lines of Botswana's borders are 4347.15 kilometres. Of these, 1544 kilometres are shared with Namibia; 1969 kilometres with SA, 834 kilometres with Zimbabwe and 0.15 kilometres with Zambia (UNIDO, 2015).

The nation lies between 17° and 27° S latitude, and 20° and 30° E longitude. The country is mainly flat, tending toward gently rolling tableland. Botswana is dominated by the Kalahari Desert, which covers up to 70% of its land surface (Africaw, 2018). Owing to the influence of the Kalahari Desert, also called Kgalagadi, there are significant temperature variations and extremes (Bauer, 2010), causing very hot temperatures during summer and very cold temperatures during winter (Africaw, 2018).

Botswana is semi-arid because of the short rainy season, with the wettest months being December to March when substantial storms are experienced. Annual average rainfall rang from 460 to 635 mm in the extreme northeast to less than 127 mm in the extreme southwest. Nonetheless, the moderately high elevation of the nation and its inland situation gives it a subtropical atmosphere. The nation is remote from moisture laden air flows for most of the year, hence is characterised by low overall humidity (UNIDO, 2015; Africaw, 2018). The dry season extends from April to October in the south and to November in the north where, in any case, precipitation sums are higher. The south of the nation is mostly presented to cool breezes amid the winter time frame (early May to late August) when normal temperatures are around 14°C. The entire nation has sweltering summers with normal temperatures around 26°C. Daylight and sunshine temperatures are high throughout the year in spite of the fact that winter is the coldest period. The entire nation is blustery and dusty during the dry season (Africaw, 2018). The Inter-Tropical Convergence Zone (ITCZ) moves southwards to around 20°S during summer, bringing moisture to the northern parts of the nation. Whatever remains of the sub-mainland is affected by a warm low-weight cell. Moist air related to the ITCZ and the wet air, which is fed into the eastern parts of the nation from the Indian Ocean, is warmed by the intense daylight, prompting convective temperature. Between May and September the steady, high pressure cell displaces the ITCZ and its related warm lows toward the north, causing drier conditions in winter (UNIDO, 2015).

Figure 1.1: Map of Botswana showing location of Gaborone and Francistown
Source: Ezilon (2009)

The Department of Metrological Services in Botswana analyses and monitors the country's regional weather, providing bulletins, weather forecasts, as well as a comprehensive range of climatological and meteorological data and reports for the country (Botswana Meteorological Services, 2014). It is the national focal point for the Vienna Conversion and the MP on substances that deplete the ozone. The Department has established a National Ozone Unit (NOU) that is responsible for coordinating all ozone activities in Botswana (Botswana Meteorological Services, 2014).

Botswana is divided into nine administrative districts, as shown on figure 1.1. The country has a population of about 2 million inhabitants with about 62% living in urban areas and about 80% the populace being gathered on the eastern side of the country (Central Statistics Office (CSO), 2011; UNEP, 2015a).

In the past, the sparsely populated country was one of the world's less prosperous countries, but recently it has experienced rapid development. Botswana is one of the world's fastest growing economies and gives direct support to its population. Gaborone is the biggest city in Botswana and additionally the financial and administrative capital of the nation, with around 10% of the country's populace. The city is situated on the banks of the Notwane River in the south-eastern corner of Botswana. The downtown area of Gaborone is an important business centre for the nation and has a semi-circular shaped area facilitating critical government workplaces. Francistown is the second largest city in Botswana and is situated 420 kilometres to the north east of Gaborone at the confluence of the Ntshe and the Tati streams and has a population 90 000 (Nag, 2017).

The climate of Botswana makes air conditioning and refrigeration a necessity in every building (Chaney, 2016). Extreme temperatures need efficiently cooled rooms during summer and warm rooms in winter. The heat wave of 2012 with maximum temperatures ranging from 43.5^{o}C to 44^{o}C, for example, increased demand for cooling systems, that is, refrigeration and air conditioning (Tlou Energy, 2012; Botswana Press Agency (BOPA, 2016; Nkemelang *et al.*, 2018), and there has been a general increased demand for HCFC-22 in the refrigeration sector and the construction sector, which require air conditioning systems and panels. The utilisation of HCFC-22 refrigerant is additionally increased by the ongoing warm summers as a result of global warming. The extensive use of HCFC-22 occurs in the air conditioning and refrigeration servicing sector, which is growing due to economic growth which has resulted in increased demand for air conditioning (UNIDO, 2015).

In Botswana, the mining sector is a major consumer of HCFC-22 where it is used in the establishment and administration of scale refrigeration and cooling hardware in mines and related procedures (Chaney, 2016). Tourism in Botswana is also an important and growing economic sector, accounting for approximately 11% of GDP. The Tourism Board has registered over 360 hotels/lodges/motels, graded from one to five star, offering excellent accommodation to support and sustain the tourism industry. With almost every room air conditioned as well as the existence of cold rooms in kitchens and in conference facilities, this may be relied on to prompt an impressive increment in future utilisation HCFC-22 in the nation (UNIDO, 2015).

1.10 **Outline of the thesis**

The thesis comprises of nine chapters which are broken down as follows:

Chapter 1: Introduction and study background

This is the introductory chapter, which positions this research within the broader framework of scientific investigations into HCFC-22 phase-out management plans. The introduction includes the background, problem statement, justification for the study, study rationale and significance, as well as the research objectives and the research questions. The components of this chapter help to connect this study to other research that has been carried out in other parts of the world and in Botswana in particular. Lastly, the chapter summarises the way the entire thesis is organised.

Chapter 2: Literature review

This chapter reviews the literature, itemised and structured into various components of the peripheral issues related to the problem, so as to gain deeper insight into the phenomenon under study.

Chapter 3: Study design and methodology

This chapter discusses the design of the study and the methodology that was employed in this research. The discussion on the methodology includes issues related to the sampling methods used and evaluates various facets of the instruments used to collect and analyse the data gathered from the study population. The main instruments used for this study were questionnaires, interviews and observations (attached as appendices). Data analysis methods are also discussed and presented, as are the measures that ensure reliability, validity and ethical standards.

Chapter 4: An evaluation of the stakeholders' level of product knowledge and awareness of HCFC-22 phase-out

This chapter analyses and presents the data gathered from the administered instruments, in line with the respondents' views and opinions. The respondents' data were analysed in line with the first objective and research question in Chapter 1 and also in line with the literature review. The chapter therefore discusses the demographic characteristic, the level of HCFC-22 knowledge of stakeholders and their awareness of the phase-out strategy. The results results on Botswana’s HCFC-22 phase-out management system are presented and discussed.

Chapter 5: Level of compliance to the Montreal Protocol resolutions on phasing out of HCFC-22 in Botswana

This chapter analyses and presents findings of the third objective of the study, which was to evaluate the level of compliance of Botswana with the MP resolutions on the monitoring, consumption and phasing out of HCFC-22.

Chapter 6: An evaluation of the achievements of the HCFC-22 phase-out milestones and the implications of HCFC-22 phase-out in Botswana

This chapter presents the results of the fourth objective of the study, which was to evaluate the milestones in the HCFC-22 phase-out trend pursuant to the Montreal summit. The evaluation focused on finding out whether importers of HCFC-22 are reducing their imports as per MP resolutions. The challenges faced in phasing out HCFC-22 were also discussed.

The chapter also presents and discusses the results of the fifth objective by, firstly, analysing the economic impact, followed by the environmental impact and, lastly, the social impact of phasing out HCFC-22.

Chapter 7: Comparison of the South Africa’s and Botswana’s HCFC-22 phase-out management strategies and implementation based on the Montreal Protocol resolutions

This chapter presents and discusses the main findings on comparing and contrasting the Botswana and SA’s HCFC-22 phase-out management strategies and implementation based on MP resolutions.

Chapter 8: Summary, conclusions and recommendations

This chapter summarises the main findings of the study, draws conclusions and makes recommendations in line with the problem statement.

CHAPTER 2

LITERATURE REVIEW

2.1 Introduction

This chapter reviews the relevant published literature and that of historical significance global, regional and organisational data, as well as industry, government and international reports and frameworks that informed, influenced and guided the philosophy, approach, methods and strategies adopted and implemented in the study. The chapter opens with a general background to the environmental challenges posed by human innovation, zeroing in on the specific twin challenges of prime interest to this study: ozone depletion and global warming. From there, a theoretical and conceptual framework is established for the study by briefly reviewing the specific frameworks that guided the study, in this case the Montreal Protocol (MP) and its subsequent amendments. From the conceptual framework the researcher illuminates and isolates the key variables investigated in the study, namely, the regulatory, non-regulatory and financial interventions implemented by the study country, Botswana (independent variable), to try and ameliorate the importation and consumption of ODSs and associated harmful emissions and in the process ameliorate the scale and effects of ozone depletion (dependent variable). Finally, a comprehensive, historical treatment of the environmental problem is given, together with the international and national responses thereto, as well as their effectiveness in curbing ozone depletion. This, among other things, helps refine the study problem and clarify the broad approach used in the study. The chapter concludes with a summary of the highlights of the literature on ozone depletion and introduces the gist of the subsequent chapter on the research methodology.

2.2 Theoretical and conceptual framework

The key framework that guided this study was the MP of 1987 and its subsequent amendments. Prior to the MP, the international response to ozone depletion took the form of a number of conventions and protocols, chief among them the Vienna Convention (VC) of 1985 and the 1997 Kyoto Protocol (KP). These are briefly described below.

2.2.1 The Vienna Convention for the Protection of the Ozone Layer (VCPOL) (1985)

The increase in the use of CFCs and the belief that CFCs lead to ozone depletion drove numerous countries of the world to sign this protocol which is referred to as the VCPOL (Middlebrook and Tolbert 2000). According to the United States Government (2002), the discovery of the rapid reduction in the ozone layer in the stratosphere over Antarctica prompted the US to participate in negotiating and ratifying the VCPOL. This convention sought to establish worldwide collaboration in investigating the ozone layer and the effects of ODSs (Ghose, 2015). Through the provisions of the VCPOL, it was expected that countries would regularly review the stratospheric ozone situation and assess the need for more regulation (Rowland, 2001).

The VCPOL was mainly a framework treaty spelling out the signatories' general obligations and structuring the global effort for dealing with the ozone depletion problem. Crucially, the VCPOL did not put specific measures in place for dealing with or restricting CFCs (Middlebrook and Tolbert, 2000; UNEP, 2001), as it merely advocated steps for future regulation and gaining a better scientific understanding of the dynamics of the ozone layer, CFCs, and halons (UNEP, 2010a), as well as declaring the need for signatories to take correct measures to shield human wellbeing and the environment from human activities with possibly unfavourable consequences for the ozone layer.

According to the UNEP (2001), 28 countries initially appended their signatures to this commitment and parties strongly agreed that the ozone layer needed protection. According to the UNEP (2015a), the agreement committed members only to acting appropriately to safeguard the environment and the health of humans from potentially ozone-destroying human activities. In response to this, the producers of CFCs did not relent easily, as they formed an alliance which advocated a responsible CFC policy. The alliance was an association representing the CFC industry, which argued that there was too much uncertainty in the science to warrant any action against the use of CFCs (Jack, 1991). Despite this alliance the VCPOL proved to be the initial step for agreements at global level to reduce halocarbon emissions (Slaper *et al.*, 1998). Despite the shortcomings of the VCPOL, it laid the foundation for the improved response strategies that came into effect under the MP in 1987.

2.2.2 The Montreal Protocol on Substances that Deplete the Ozone Layer (1987)

The MP recognised that the depletion of the ozone layer is an issue that affects the entire world and which transcends national borders; hence, the MP called for concerted international cooperation (Ghose, 2015). The MP brought a paradigm shift to the hitherto largely unregulated and fragmented global refrigeration and air conditioning (RAC) sector (Velders *et al.*, 2012) and, unlike the VCPOL, is a legally binding document which mandated signatories to scale down their use of CFCs and other ODSs. Each signatory had to craft a phase-out plan for HCFC-22, with specific milestones to be observed towards eventual complete phase-out of ODSs and their associated equipment. Later, in 1990 and 1992, amendments were made to the MP in London and Copenhagen, which set the elimination date for CFCs in Non-Article 5 for developed countries as 1995 (Ghose, 2015). The London amendment and the Copenhagen amendment, in addition to accelerating the phase-out of all of the identified ODSs by the year 2000, also broadened the number of controlled substances to include completely halogenated CFCs, methyl chloroform and carbon tetrachloride (Finas, 2003), and set the complete phase-out of methyl chloroform as 2005 (UNEP, 2001). Additionally, the Copenhagen amendment added HCFCs, developed as a substitute for CFCs, to the list of restricted substances and made their gradual phase-out by 2030 mandatory (Wang *et al.*, 2016). The Beijing amendment classified HCFCs as transitional substances (Wang *et al.*, 2016) whose complete phase-out was to occur by 2020 in developed countries and by 2040 in developing countries (Middlebrook and Tolbert, 2000).

2.2.3 The Kyoto Protocol

The KP was signed in 1997 in Kyoto and was added to the United Nations Framework Convention on Climate Change (UNFCCC). The signatories committed to numerically specified and legally binding limits on or reductions in GHG emissions to 1990 levels (Rosenqvist *et al.*, 2003) in line with the London Amendment of the same year. The baseline was based on six specific GHGs, as agreed to in the 1990 London Amendment. The specific gases the emissions of which were to be reduced were methane (CH_4), carbon dioxide (CO_2), nitrous oxide (N_2O), perfluorocarbons (PFCs), HFCs and sulphur hexafluoride (SF_6) (Rosenqvist *et al.*, 2003; Sandler, 2017). The KP aimed to reduce GHG emissions by 5.2%, which was to be achieved during the period 2008–2012 (Velders *et al.*, 2007). However, the chemical corporations exerted extensive influence, hence the failure of governments to take the available precautionary measures. Moreover, prior to the signing of the KP, the signatories to the MP had elected not to consider the global warming impacts of CFC replacement substances (UNEP, 2010b).

2.2.4 The Kigali Amendment (2016)

The Kigali Amendment specifies a reduction of 85% in HCF usage in developed or Non-Article 5 countries between 2019 and 2036. The corresponding targets for developing or Article 5 countries are an 85% HFC phase-down between 2024 and 2047, with deferred implementation targets for selected Article 5 parties (European Fluorocarbons Technical Committee (EFTC), 2017). The Kigali Amendment created a legally binding multilateral agreement to control the production and consumption of HFCs at regional and national levels (Velders *et al.,* 2012). With a focus on controlling global warming, it grouped countries and their corresponding milestones and obligations according to their climate as well as the extent of development and sought to support the long-run goals articulated in the Paris Agreement of constraining global temperature increments to well below 2 °C above pre-modern levels (specifically 0.06 °C) (Streck *et al.,* 2016). Seki (2017) likewise notes that the Kigali Amendment made financial resources available to African nations that selected to phase out the gases quicker than required in view of the grave dangers facing the region as a result of the change.

2.2.5 Conceptual framework

The structuring of Botswana’s hydrochlorofluorocarbon phase-out management plan (HPMP), like those of fellow signatories, was guided by the MP and its subsequent amendments. The MP prescribed a set of regulatory, non-regulatory and funding/resourcing interventions to be incorporated in the country-level (signatory) phase-out plans. As illustrated in Figure 2.1, the regulatory interventions included the crafting and enforcement of legislation on the importation, exportation, use and disposal of HCFCs and other ODSs, as well as their associated equipment, and penalties for the violation of these provisions. Non-regulatory interventions largely revolve around the capacitation of stakeholders through training and information exchange, awareness-raising among key stakeholders and research into more environmentally friendly alternative refrigerants. Key stakeholders included importing companies, refrigeration technicians, customs authorities, refrigeration and air conditioning (RAC) associations, as well as final users of the refrigerants and air conditioning. This also involved the carrying out of mitigation and vulnerability studies and additional refinements of the respective countries’ inventory of GHGs.

To facilitate the above two interventions, a third set of interventions was necessary, namely funding. This entailed appropriate financial mechanisms through the international funding bodies established under the MP. Specifically, these funding mechanisms were tailored to enable the MP signatories to fulfil their obligations as per the protocol in terms of general funding of the HPMP, providing incentives for users, technology transfer, strengthening of retrofitting/disposal activities, and training and information dissemination initiatives.

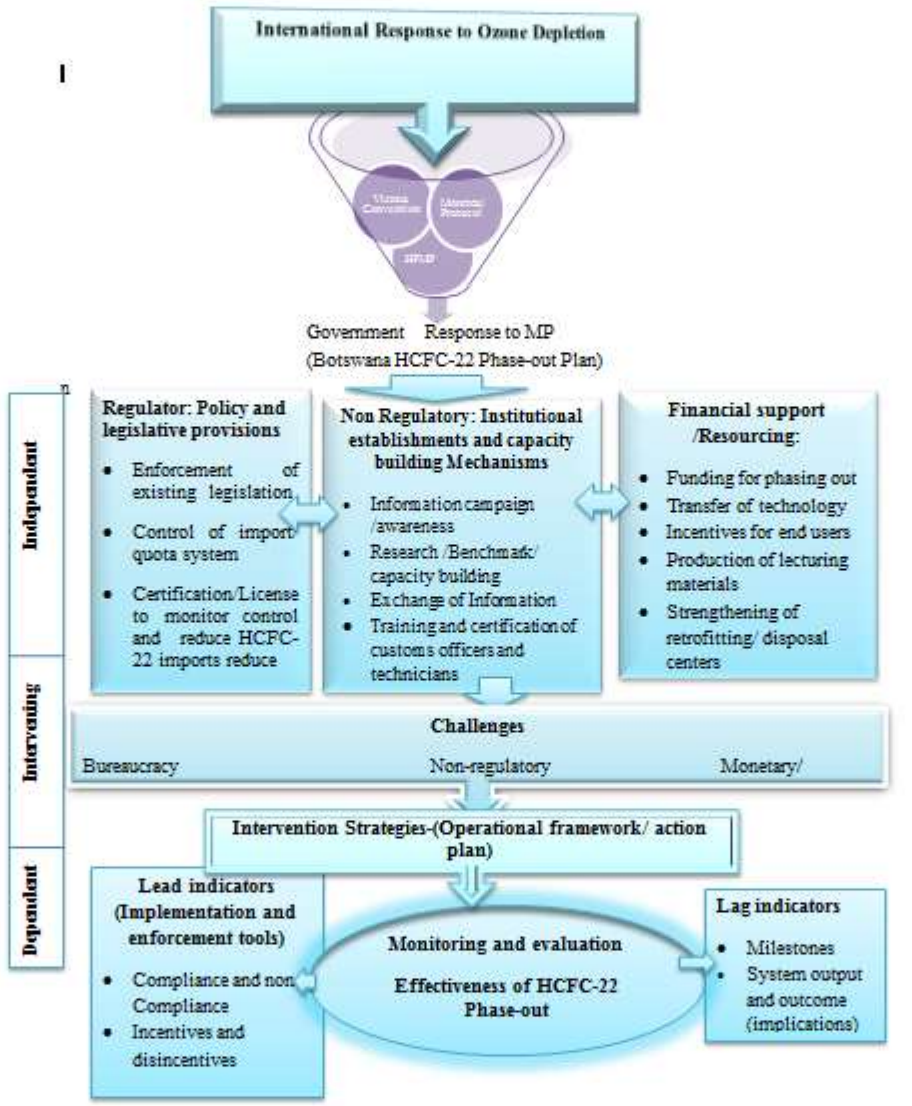


Figure 2.1: Conceptual framework for phasing out HCFC-22 in Botswana
Source: Researcher's own illustration

These three sets of interventions are considered to be the independent variables which determine the effectiveness of the country's HCFC-22 phase-out plan. The expected outputs of the HPMP can be measured in terms of both lag and lead indicators, which the researcher categorises as dependent variables. The lead indicators include, inter alia, the extent of alignment between the country's HPMP with the specifications set out in the MP and its amendments, the extent of enforcement of legislation on the control of importation and consumption of ODS, and the application of funding provided to the country to enable it to meet its obligations. The ultimate lag indicator is the extent to which HCFC-22 importation and consumption milestones are being met by the country.

In between the predictor and outcome variables are the intervening variables which have the effect of moderating the impact of the independent regulatory, non-regulatory and financial interventions. Practically, these reflect the various challenges encountered by the country in conceptualising and operationalising its HCFC-22 phase-out plan.

2.3 **The ozone layer and its socio-ecologocal significance**

Evidence has overwhelmingly shown that there is a belt of naturally occurring gas called the ozone layer which shields the dangerous UV-B released by the sun (Ebojie, 2009; Bolaji, 2011; Sivasakthivel and Reddy, 2011; EPA, 2015). Ozone is the gas that stops UV-B from reaching the earth. This section presents basic information on ozone and the ozone layer that will help to understand and support the need to phase-out ODSs.

2.3.1 Ozone and the ozone layer

Ghose (2015) describes ozone (O_3) as a molecule composed of three atoms of oxygen (O) which is generally found in the stratosphere where it shields creation on the ground from the sun's unsafe UV-B radiation. Lin *et al.* (2019) provide the same definition of ozone and state that it is naturally present in earth's atmosphere and is a gas that has markedly different effects depending on various locations. Fahey (2013) defines ozone (O_3) as a major chemical component of the atmosphere which protects living organisms by shielding the earth from the sun's dangerous UV-B radiation.

Aggarwal *et al.* (2013) and Williams *et al.* (2019) explain that ozone is a result of the build-up of rising atmospheric oxygen concentrations over more than two billion years, which gradually led to the formation of the atmosphere. They additionally suggest that the production of ozone is as a result of the photo dissociation of oxygen by high energy solar photons in the stratosphere, a process which prompts the release of single oxygen atoms which later combines with intact oxygen molecules to form ozone. Similarly, Sivasakthivel and Reddy (2011) point out that ozone has built up on the earth over 3000 million years because of the increase in primitive types of vegetation. This kept on producing little measures of oxygen through the photosynthesis response which changes carbon dioxide into oxygen.

The bulk of ozone originates at the equator where sunshine concentration is highest, but it migrates at high altitude as a result of winds and is accumulated in the stratosphere (Ebojie, 2009; WMO, 2011; Anwar *et al.*, 2016; Williams *et al.,* 2019). Bolaji (2011) confirms that the vast majority of the ozone resides in the stratosphere, the upper part of the atmosphere which is at least 10 kilometres above earth’s surface. Bolaji (2011) further points out that the stratospheric ozone, which is also referred to as good ozone, is naturally found in the upper stratosphere. The World Meteorological Organization (WMO, 2008) has published the results of a study suggesting that the stratosphere is the layer lying 10 to 48 kilometres above the earth’s surface. This literally means that most of the ozone is naturally created in the stratosphere. Sivasakthivel and Reddy (2011) stress that although ozone can be found throughout the atmosphere, the highest concentration is found at altitudes ranging from 19 to 30 kilometres. The National Aeronautics and Space Administration (NASA) Earth Observatory Team (NASA, 2014; 2016) also provide similar observations, although there is a slight difference between the estimates of where the ozone layer lies. Haar (2016) claims that stratospheric ozone is in the range 15 to 50 kilometres above the ground, acting as a shield that protects the earth’s surface from the sun’s dangerous UV-B radiation. Thus, without ozone, the sun's extraordinary UV-B radiation would clean the surface of the earth, hence the reference to ozone as a protective layer. Sivasakthivel and Reddy (2011) and Langematz (2019) additionally assert that more than 91% of the ozone is situated in the lower part of the stratosphere from around 15 to 35 kilometres above the earth's surface. The probable reason for the variation according to Lucas and Gies (2011) is the fact that the thickness changes seasonally and by geographical location. As indicated by the WMO (2008) and the EPA (2010), the circulation of aggregate ozone over the earth changes with area in terms of timescales that range from every day to occasional. The EPA (2006) further posits that the differences are a result of substantial scale chemical production, stratospheric air movements and ozone destruction. The aggregate ozone is regularly most reduced at the equator and is greatest over the poles.

Ozone occurs at two levels in the form of tropospheric ozone and stratospheric ozone; the tropospheric zone differs with differences in daylight (Aggarwal *et al*., 2013; EPA, 2018; Williams *et al*., 2019). Ozone close to the ground is a contaminant and its creation is enhanced by air contaminants, as well as nitrogen oxides and volatile compounds (Cooper *et al.,* 2014; Paoletti *et al.,* 2014). At higher levels in the atmosphere, however, ozone plays a more benign role: in the stratospheric layer, ozone screens out cell destructive UV-B incoming radiation from the sun (Nunez-Pons *et al.,* 2018). Changes in weather conditions and in solar energy release and the impact of major volcanic eruptions directly affect the natural concentration of ozone in the stratosphere (Ghose, 2015). According to the UNEP (1996a), Tian and Juan (2009), Liopis *et al.* (2011) and Aggarwal (2013), the ozone layer absorbs harmful UV solar radiation, thus shielding plant and animal life from UV-B. The WMO (2010) and Nunez-Pons *et al.* (2018) further suggest that the slant path density and thickness of the ozone layer decreases the intensity of the UV-B radiation as it touches the surface of the earth.

Turekian (1996) maintains that life on earth has been sheltered for a great many years by this life-securing layer which has properties that absorb the most harmful UV-B radiation, which is destructive to living matter, from the sun. It prevents the radiation from touching the surface of the earth and thus shields it from the unsafe effects of radiation (Ritchie and Roser, 2018; Langematz, 2019). Hence, it regulates the temperature of the earth by screening UV-B radiation, thereby creating a controlled environment for humans and animals and helping to preserve life on the planet (Southern African Research and Documentation Centre (SARDC), 1994, UNEP, 2001). Karentz (2008), WMO (2010) and Nunez-Pons *et al*. (2018) postulate that the ozone layer also absorbs adequate short-wavelength radiation to preserve the safe ambient UV-B levels.

NASA (2014) and Anwar *et al*. (2016) contend that the thickness of the ozone layer additionally differs with seasonal change and altitude and that ozone layer concentration is somewhere in the range of 19 and 23 kilometres. Similarly, Bolaji and Huani (2013) describe the ozone layer as a delicate shield of gas that lies between 10 and 55 kilometres above the earth surface and its thickness changes according to location and season. There seems to be a difference in the coverage of the ozone layer though not significant. Regrettably, the ozone layer has been actively diminished by human activity in the past 60 years with its associated chemical reactions, especially over Antarctica every spring (WMO, 2011; Nunez-Pons *et al.,* 2018; Ritchie and Roser, 2018; Langematz, 2019).

2.3.2 The ozone layer depletion and the ozone hole

Ozone depletion refers to two distinct but connected phenomena which have been observed since the late 1970s: a consistent decrease of about 4% every decade in the aggregate volume of the ozone layer and a significantly much greater spring decrease in stratospheric ozone over the polar regions (Maheshwari, 2013; Cooper *et al.*, 2014; Ritchie and Roser, 2018; Langematz, 2019). According to the UNEP (1996a), comprehensive measurements of the ozone layer began in 1957. Since the late 1970s, scientists continuously measured the ozone layer, using instruments that are balloon borne, satellite borne and ground based (Munasinghe and King, 1992; Chipperfield *et al.*, 2015; Deshler *et al.*, 2017). The world over, there is the concern that the depletion of this layer is threatening the existence of life on the earth (Llopis *et al.*, 2011). Stratospheric ozone depletion is a serious problem for the whole planet because thinning exposes all life to uncompromising consequences (Munasinghe and King, 1992; Calm, 2008; Boumaza, 2010; Strahan and Douglass, 2018; Ritchie and Roser, 2018; Langematz, 2019).

The last couple of decades have seen notable degradation of the ozone layer due to anthropogenic emissions of ODSs containing bromine and chlorine atoms, substances that chemically destroy stratospheric ozone (WMO, 2011; Doglioni *et al.*, 2016; Nunez-Pons *et al.*, 2018; Ritchie and Roser, 2018; Langematz, 2019). The most serious depletion has happened in the polar regions and is generally referred to as the Antarctic ozone hole, first detailed in 1987 (WMO, 2010). This regular, seasonal loss of ozone has increased surface UV-B in the Antarctic and surrounding areas and has resulted in changes in surface winds and temperatures at high southern latitudes (Fahey, 2013, Cooper *et al.*, 2014; Andrady *et al.*, 2017).

Several scientific studies (Molina and Rowland, 1974; EPA, 2001; Rowland, 2001; Calm, 2008; Nunez-Pons *et al.*, 2018; Ritchie and Roser, 2018; Langematz, 2019) have shown that the ozone layer is diminishing because of the emission of CFCs and bromides from anthropogenic chemicals into the atmosphere. Similarly, Calm (2008), Mogola (2008), WMO (2011; 2018) and Nunez-Pons *et al*. (2018) concur that natural air movements convey these collected gases (CFCs, halons and bromides) in the stratosphere, where they are changed to more receptive gases that ultimately cause ozone layer depletion. The general diminution of the ozone layer has been recorded as a yearly increment of 0.5% since 2000 owing to the widespread utilisation of ODS in the manufacturing of hard and soft foam propellants and refrigerants in cleaning solvents, air cooling and refrigeration (Rozema *et al.*, 2005; WMO, 2015; 2018). From the 1970s to the turn of the century, manufactured halogenated compounds declined by 6% to 3% in stratospheric ozone levels over the temperate and tropical latitudes (60° N-60° S) (Karentz, 2008; Tiwari and Agrawa, 2018). Further estimates of ozone layer depletion amount to an average of 4 to 5% per decade (UNEP, 1996b; Aggarwal *et al.,* 2013; Fahey, 2013; Ritchie and Roser, 2018).

According to the UNEP (1996a), measurements taken between 1979 and 1991 indicated noteworthy patterns in the sum total of ozone over the tropics (20° N–0° S) and no critical degradation at any altitude ranging from 25 to 30 kilometres. According to Karentz (2008), measurements at altitudes of 35 to 45 kilometres suggest rates of ozone depletion of 5 to 10% per decade in the tropics and below 20 kilometre altitude. There is thus inconsistency between measurements, with the EPA (2006) suggesting trends over the mid-latitudes of as much as 20% per decade. The WMO (2011) has stated that in the Northern Hemisphere mid-latitudes over the period 1979-1994, ozone levels fell twice as quickly in winter as in the summer, which suggests that ozone depletion varies with the season. The WMO (2018) also noted less seasonal variation in the Southern Hemisphere.

Interestingly, while opinions on ozone depletion seem to be the same, there are varied observations over various locations. According to Maheshwari (2013), the leader of the National Ozone Center in New Delhi, there is no pattern to demonstrate total depletion of the ozone layer over India. Regardless of the suggestions that there was no ozone depletion over India, Kulshresta and Thaphyal of the Indian Meteorological Department (1992) asserted that for the period 1956-1986 ozone estimations displayed year to year constancy, but did not demonstrate any expanding or diminishing pattern over India (Maheshwari, 2013).

In Australia, Synthetic Gas Team Australia (2007) collected and recorded data on the upper atmosphere that demonstrated that there has been a general diminishing of the ozone over most of the earth. This collected data reflects 5 to 6% ozone depletion over Australia since the 1960s, which has increased the risk that the Australians already encounter from overexposure to UV radiation resulting from their outdoor lifestyle. Researchers in Taiwan, China, also affirmed that CFC outflows cause depletion of the ozone layer (Asian and Pacific Center for Transfer of Technology (APCTT), 2010). The anthropogenically driven ozone depletion from 1960 to 1980 ranges from 26.43 to 49.86% of the aggregate anthropogenic ozone depletion from 1960 to 2000 (Langematz *et al.,* 2016). An even stronger ozone decline of 56.46% was estimated from ozone observations. The examination of the observations and the simulations of chemistry climate model (CCMs) show that while the return of Antarctic ozone to 1980 quantities remains a substantial turning point, accomplishing that milestone does not show full recuperation of the Antarctic ozone layer from the impacts of ODSs (Langematz *et al*., 2016).

According to the APCTT (2010), research was conducted that precisely measured chlorine peroxide produced when CFCs decay in a laboratory environment. Chlorine peroxide has long been thought to trigger ozone depletion as the larger the absorption cross segment of chlorine peroxide, the faster chlorine peroxide absorbs sunlight and the faster chlorine atoms are generated, depleting the ozone layer at a rapid rate. This fundamental theory was challenged, however, by Pope *et al*. (2007), who presented contradictory data after measuring absorption. Pope *et al.* (2007) tested the photolysis rate of chlorine peroxide and found that it was around ten times lower than that already acknowledged. This suggests that it is difficult to deliver enough chlorine atoms to ascertain the level of ozone lost and observed by any other chemical means. Despite the observations by Pope *et al*. (2007), there is overwhelming evidence that there is indeed depletion occurring and that CFCs are significantly contributing to the depletion of the ozone layer (Montzka *et al.,* 2018; Prinn *et al.,* 2018; Rigby *et al.,* 2019).

The ozone hole is located in the stratospheric zone in which ozone depletion has occurred (Ungar, 2000; Petrescu *et al.,* 2018; WMO, 2018; Adeoye and Aina, 2019). Ghose (2015) reveals that following a realisation in the late 1970s of the detrimental effects of man-made emissions of CFCs on the ozone layer, an even worse discovery was made in the spring of 1985: the existence of an ozone hole in the stratosphere over the continent of Antarctica. NASA (2014) describes the Antarctic ozone hole as a region characterised by losses ranging from 50 to 90% of the aggregate section measure of ozone in some levels within two to three months. Technically though, the existence of the ozone hole does not literally mean the complete absence of ozone in any part of the stratosphere (NASA, 2014). Rather, it is a metaphor for a zone in the atmosphere where the rate of concentration is below 220 Dobson units (DU). Anwar *et al*. (2016) put this figure at a threshold of 200 DU. The 220 DU is a historical figure from pre-depletion times when concentrations were much higher (Rozema *et al.,* 2005; Chipperfield *et al.,* 2015; NASA, 2016).

Accordingly, data recorded in the 1970s in Antarctica reflects that this was the first ozone hole. This data on the ozone hole discovery is consistent with more discoveries made in 2000 in the Arctic region (Angell and Korshover, 2005). Based on the fact that the ozone hole relates to the depletion of the layer, then it means that the ozone hole is not really a "hole" but a thinning of the ozone layer (Ungar, 2000; Andersen *et al.,* 2018; Hegglin, 2018). However, the phrase "ozone hole" was and often still is used too far loosely (WMO, 2011). Frequently, the term is employed to describe any episode of ozone depletion no matter how minor (Rozema *et al*., 2005). What are considered to be normal levels of concentration of ozone approximate 300 to 350 DU (Haar and Allen, 2015; WMO, 2015; Orphal *et al.*, 2016; Adeoye and Aina, 2019).

According to Sivasakthivel and Reddy (2011), ozone loss occurs during spring above Antarctica, and slightly less so over the Arctic, where unique climatic and weather conditions and depressed air temperatures increase the destruction of ozone by anthropogenic ODSs. In late September 2009, the Antarctic ozone hole achieved its 2009 pinnacle periphery as indicated by estimations by analysts at the National Oceanic and Atmospheric Administration (NOAA) of the United States (NOAA, 2009).

Since the ozone hole was initially discovered in the 1970s, signs are that this hole, which appears annually in September over Antarctica, is ever expanding and deepening; this phenomenon is attributed by the WMO (2011) and Kloss *et al.* (2014) to the proliferation of bromine and chlorine containing substances in the 1980s and 1990s. The timing of this phenomenon is explained by the return of the sun's rays in August/September after months of sunlessness. The sun's rays cause catalytic reactions which lead to more reactive versions of chlorine and bromine being produced and created and then focused over the South Pole in winter. It is these responses which quickly degrade molecules of ozone (Haar, 2016). Even more worrisome is the huge depletion zone over the Arctic which is near the more populous regions of the Northern Hemisphere. Fahey (2013) details the annual behaviour of the Antarctic ozone hole even more graphically. The author says the polar phenomenon accounts for the biggest annual ozone loss at roughly 60% towards the end September and the beginning of October every year, above a land area of 25 000 000 km^2. Thereafter, ozone concentrations are restored to the Antarctic region as ozone rich air moves in from the lower altitudes. It is projected that these losses will be sustained for several decades until ODS levels are naturally reduced.

Marginally smaller than the North American mainland, the ozone hole covers approximately 24.1 million km^2, as indicated by NOAA satellite observations on 11 September 2014 (Haar and Allen, 2015; Haar, 2016; Fernandez *et al.*, 2017). On 2 October 2015, the ozone hole reached its peak of 28.2 million km^2 and this positions this as the fourth largest satellite estimation compared to the 1991-2014 period (Haar and Allen, 2015). The extent of the ozone hole was about 8.9 million square miles in 2016, having grown in 2015 to 10.9 million square miles (Haar, 2016). Relatively warmer temperatures in 2016 constrained the expansion of the hole, while colder than average temperatures in 2015 amplified it. According to the Synthetic Gas Team Australia (2007), more damage occurs above Antarctica every spring with the formation of the ozone hole. The group likewise recorded the Antarctic ozone holes in 2000 and 2006 as the biggest on record, estimating around 32.9 million km^2, which is more than three times the extent of Australia. The ozone holes that were observed in 2003 and 2007 were significantly smaller, largely because of the disturbance of the gap by other climatic conditions in the troposphere and stratosphere (Muller *et al*., 2007; Synthetic Gas Team Australia, 2007; Livesey *et al.*, 2015; WMO, 2015; Griffin *et al.*, 2019).

The Intergovernmental Panel on Climate Change (IPCC, 2001) state that the Antarctic ozone hole has a relatively small impact on global ozone; every year when the Antarctic ozone hole breaks down, the air with diminished ozone concentration drifts out into the neighbouring regions. Muir (2008) likewise revealed monthly decreases in the ozone level of up to 10% in New Zealand subsequent to the breakup of the Antarctic ozone hole. McKenzie *et al*. (1999) added that this has resulted in UV-B radiation concentrations increasing by more than 15% since the 1970s.

On a more positive note, there are signs of improvement in the ozone depletion phenomenon. In 2016, for the very first time, direct satellite observations of the ozone hole revealed that concentrations of ozone depleting chlorine were declining, reducing the rates of ozone loss. This positive trend is a result of the international ban on man-made CFCs (Andersen *et al.*, 2018: Petrescu *et al.*, 2018; Wilmouth *et al.*, 2018). Compared to 2005, when NASA's Aura satellite first measured chlorine and ozone levels during the Antarctic winter, 2016 showed a decline in ozone depletion of about 20% (Haar, 2016; NASA 2018; Petrescu *et al.*, 2018). Krummel and Fraser (2017) also recorded a decrease to 15.3 million km^2 in the daily ozone hole area during the third week of September 2017. This 2017 decrease was recorded as well below the 1979-2016 average. Krummel and Fraser (2017) further noted that during the third week of October 2017, the daily ozone hole area continued to decrease, dropping to 10.4 million km^2 on 27 October 2017.

2.4 **Causes of ozone depletion**

Most research and empirical evidence has suggested that ozone layer depletion is taking place (WMO, 2015; Petrescu *et al.*, 2018; Wilmouth *et al.*, 2018*;* WMO, 2018; Barnes *et al.*, 2019).

Life on the surface of the earth is under threat as a result of the widening of the ozone hole. While ozone layer depletion has been linked to the emission of CFCs (Montzka *et al*., 2018; Prinn *et al*., 2018), it is worth reviewing the literature in relation to the main causes as well as other fundamental drivers that result in damage to the ozone layer. There are various causes of ozone layer depletion; some result from natural phenomena and others are as a result of human activity (Andersen *et al.,* 2018; Prinn *et al.,* 2018; Wilmouth *et al.,* 2018). However, according to Molina and Rowland (1974), Sivasakthivel and Reddy (2011) and Cao *et al.* (2016), the causes that pose the most significant risk of depletion result mainly from human activity, hence, the literature review will focus more on anthropogenic causes.

2.4.1 Natural threats to the ozone layer

Ghose (2015) posits that the degradation of the ozone layer is taking place because the natural rate of ozone generation is outstripped by its natural destruction. Some of the natural bromine containing compounds responsible for ozone depletion emanate from various substrates such as the ice/snow-covered surfaces in the Arctic (Cao *et al.,* 2016).

2.4.1.1 *Volcanic eruptions*

As indicated by the EPA (2010), Carn *et al*. (2016), Ivy *et al.* (2017) and Brenna *et al.* (2019), it is believed that the major volcanic emissions from El Chichon in 1983 and Mt Pinatubo in 1991 also contributed to the depletion of the ozone. Volcanoes have been found to be one of the key factors that contribute to the broadening of the ozone hole (Portmann *et al.,* 1996; Kutterolf *et al.,* 2013; Kutterolf *et al.,* 2015; Ivy *et al.,* 2017). Ashraf (2008) revealed that as volcanoes erupt, they release substantial amounts of aerosols as well as limited amounts of chlorine into the troposphere. Consequently, Nash (2007), Polvani *et al*. (2017) and Brenna *et al.* (2019) revealed that large volcanic explosions directly affect the ozone layer and change the weather patterns globally and in turn affect the Antarctic ozone hole. Klobas *et al.* (2017) and Brenna *et al.* (2019) also observed that the large volcanic eruption (Mt Pinatubo) in 1991 increased the ozone hole by 20% more than before, so the eruption of large volcanoes increases the frequency of occurrence of the ozone hole. Self *et al*. (1993), Solomon *et al.* (2016) and Brenna *et al.* (2019) concur that the large Mt Pinatubo volcanic eruptions in 1991 had extensive and uneven ozone depleting effects in the Antarctic zone. This is due to the release of sulphur, which increased the surface areas of liquid polar stratospheric clouds and aerosol particles. The seasonal temperature and transport as well as volcanic aerosol variations aside, the month of October exhibits the most noticeable reduction in ozone concentration of any month in the

Antarctic (Solomon *et al.*, 2016; Ivy *et al.*, 2017). In fact, going forward in the near future, while ODS-related levels of chlorine remain high, possible volcanic eruptions are expected to continue playing a key role in ozone levels, alongside emissions of GHGs. The WHO (2015) states that the effects of volcanic eruption are expected to continue over much of the earth. To stress the importance of volcanic eruptions it was pointed out that despite expected reductions in ODSs pursuant to the MP, and a consequent increase in Antarctic ozone and a decrease in UV radiation, volcanic eruptions will from time to time slow down the repair process (Aquila *et al.*, 2012; Environmental Effects Assessment Panel (EEAP), 2017; UNEP, 2015c, 2017a). The spring of 2015 for instance saw increased South Pole ozone losses following the eruption of the Calbuco volcano in Chile (Solomon *et al.*, 2016).

2.4.1.2 *Stratospheric winds*

Stratospheric winds are winds in the stratosphere and the mesosphere (Nash, 2007). The ozone layer has additionally been observed to be influenced by certain characteristic phenomena, for example sunspots and stratospheric winds (EPA, 2010; Gabriela *et al.*, 2018; Madhu and Sudo, 2019). Be that as it may, this has been found to cause not more than 1 to 2% of the ozone layer depletion and the effects are also thought to be temporary. Nash (2007) and McLandress and Shepherd (2010) agree that stratospheric winds as a cause of ozone depletion do not cause a significant depletion as the alteration of winds assists in expanding the ozone value at a particular latitude by only approximately 3%.

Nash (2007) and Brown (2019) also observed that every 26 months stratospheric winds in the lower stratosphere alter from east to west and back again to the same place. This event is called quasi-biennial oscillation. Such variations in the earth's atmosphere influence the fate of the ozone layer since stratospheric ozone is affected by changes in temperatures and winds in the stratosphere (Rao *et al.*, 2015; Bias *et al.*, 2018; Pedatella *et al.*, 2018). The UNEP (2006) and Robinson and Erickson (2015) clarify that the lower temperatures and more strongly grounded polar winds both influence the degree and seriousness of winter polar ozone depletion. The UNEP (2013a), Bias *et al.* (2018), Wilmouth *et al*. (2018) and Langematz (2019) recommend that while the world's surface is expected to warm in light of the net positive radioactive force from GHGs, the stratosphere is relied on to cool and this will broaden the period over which polar stratospheric clouds are available in the polar regions, thus causing winter ozone depletion.

UNEP (2013a) and Bornman *et al.* (2015) project far-reaching results for biological ecosystems emanating from shifts in circumpolar westerly winds. Beyond the influence of stratospheric winds on water availability and wind speeds, it is anticipated shifts in the Southern Hemisphere circulation processes will prompt hotter summers in South America, further fuelling the expansion of the ozone hole (Bias *et al.,* 2018; Williamson *et al.,* 2019). A strong correlation between the two phenomena was observed during the period 1993–2000, sometimes called the large ozone "hole" era (Manatsa *et al.*, 2013; Chipperfield *et al.*, 2017).

2.4.2 Anthropogenic threats to the ozone layer

The human appetite for improving standards of living has resulted in humans becoming serial climate change agents. This has resulted in many technological advances in various practices, processes and products, amongst other things, in order to improve the living environment. Many paradigm shifts have significantly benefited humanity as a result of turning a blind eye to the negative effects of inventions and innovations (Turekian, 1996; Andersen *et al.,* 2018; Langematz, 2019). Advances in technology and innovation have resulted in the generation and emission of compounds that never existed before and which are harmful to the atmosphere. The following are some of the activities and compounds that are man-made and are negatively affecting the ozone layer.

2.4.2.1 *Rocket launches*

Rocket launching has been identified as being among the major cause of ozone depletion and climate (Sivasakthivel and Reddy, 2011; Anwar *et al.,* 2016; Jindal *et al.,* 2018*;* Ross and Vedda, 2018; Sharma, 2019; Verbeek and Fouquet, 2020). According to Dallas (2020), rocket launches are the only source of ODSs that are directly deposited into the stratosphere. Since 2018, the rocket launch business has significantly grew with an annual increase of 25% since 2017 (Grush 2018; Ross and Vedda, 2018; Verbeek and Fouquet, 2020). Ross and Vedda (2018) further estimate that, rocket launches globally inject 11 000 tons of soot and alumina particles into the atmosphere annually. This increased number of rocket launch could significantly deplete the ozone layer.

Currently, the MP is not controlling rocket launching activities as opposed to the overwhelming response to the ability of CFCs to deplete the ozone. According to Ross *et al.* (2009), Sivasakthivel and Reddy (2011) and Sharma (2019), if rocket launches continue unregulated they have the potential to cause a huge loss of ozone by the year 2050. Nevertheless, Ross *et* *al.* (2009), Anwar *et al.* (2016) and Talwar (2018) suggest that current worldwide rocket emissions deplete the ozone layer by close to a couple of hundredths of 1% every year. These are some of the studies that have dismissed the ozone depletion potential (ODP) of rocket launching activities. The observation that global rocket launches have little effect on ozone depletion is questionable as rocket launching is definitely contributing to the growth of the space industry. As a result, the potential for ozone depletion as a result of rocket launches should be a contemporary issue (Kruger *et al.*, 2010; Anwar *et al*., 2016; Jindal *et al*., 2018; Ross and Vedda, 2018).

Ozone depletion has also been attributed to emissions into the stratosphere of large amounts of nitric oxide (NO) and nitrogen dioxide (NO_2) gas by supersonic planes (Ghose, 2015; Sharma, 2019). Supporting data has come from new measurements of chlorine compounds in Taiwan, in Malaysia and from a plane traversing the skies of South East Asia (Ghose, 2015). Evidence from these measurements points to the fact that these emissions are significant, and that they get blown into the upper troposphere in the tropical region. However, the role of these chlorine compounds in ozone depletion is considered insignificant and temporary, as they account for a small portion of stratospheric chlorine, the bulk of which comes from the stable, more enduring CFCs, methyl chloroform (CH_3CCl_3) and carbon tetrachloride (CCl_4) (Oram *et al.*, 2017). Pitari *et al.* (2015) concur on the minor contribution of aircraft emissions of sulphur and aerosols to ozone depletion, especially when these are considered in isolation.

2.4.2.2 *Chlorofluorocarbons (CFCs)*

The agents responsible for most ozone depletion are now generally recognised to be man-made compounds like CFCs, also called industrial halocarbons, which were first identified in 1974 by Dr S Rowland and Dr M Molina (Molina and Rowland, 1974; Sivasakthivel and Reddy, 2011; Andersen *et al.*, 2018; Wilmouth *et al.*, 2018; Langematz, 2019). The anthropogenic CFCs, were reported to be the fundamental drivers of ozone degradation. According to Rowland (2001), reports from NASA and the WMO Ozone Trends Panel in March 1988 indicated that the chlorine free radicals produced by CFCs were basically responsible for the Antarctic ozone hole and the significant winter time ozone losses registered by ground stations in the United States, Europe, and Japan. This is consistent with the research of Lucas and Gies (2011) and Langematz (2019), who also suggested that it was not until the mid-1970s that researchers initially suggested that CFCs, inactive at ambient temperatures, could turn into an intense wellspring of exceedingly responsive free chlorine radicals which cause ozone layer depletion. Mogola (2008) additionally depicted CFCs as a class of gases containing a mixture of carbon, hydrogen, chlorine and fluorine gases used mainly as refrigerants and propellants in aerosols, while halons are unreactive vaporous mixtures of carbon with bromine and different incandescent light used in firefighting, which are now known to deplete the ozone layer. Kloss *et al.* (2014) and Wilmouth *et al.* (2018) describe CFCs as trace gases whose breakdown in the presence of ultraviolet radiation in the stratosphere produces chlorine (Cl) radicals, which in turn catalytically degrade ozone (O_3) molecules. Ashraf (2008), Ravishankara *et al.* (2009), Labacher (2017) and Langematz (2019) concur that CFCs and other halogenated ozone damaging substances are principally responsible for man-made ozone depletion. Previdi and Polvani (2014) attribute stratospheric ozone depletion to anthropogenic emissions of rare gases, mainly CFCs, as well as other chlorine and bromine-containing compounds (halogenated compounds). In the presence of sunlight, they change into active forms that destroy ozone, a phenomenon prevalent on the surface of stratospheric clouds in the polar region and Antarctic lower stratosphere at altitudes of approximately 12 to 25 kilometres during austral spring.

Since their first synthesis in 1928, CFCs have been used as dry cleaning agents, hospital sterilants, industrial solvents, refrigerants in home appliances and in vehicles manufactured prior 1995 (EPA, 2010; Lucas and Gies, 2011). About 80% of CFC global emissions occur in northeastern Asia, specifically China mainland (Vollmer *et al*., 2018). The increase in CFCs emissions from China is a result of new production and use, which is inconsistent with the MP agreement to globally phase-out global production of CFCs by 2010 (Rigby *et al*., 2019). However, the important point to note is that the CFCs in the products only become harmful when they are exposed to the stratosphere. The threat of CFCs was not considered important until the revelation of the ozone opening over Antarctica in 1985 (Sivasakthivel and Reddy, 2011). Even then, the damaging potential of CFCs was not taken seriously especially in view of the fact CFC emissions have accounted for approximately 60 to 80% of aggregate stratospheric ozone layer destruction (Sivasakthivel and Reddy, 2011;Bolaji and Huan, 2013;Montzka *et al.*, 2018: Ritchie and Roser, 2018; WMO, 2018) Montzka *et al.*, 2018). CFCs are exceedingly volatile and non-combustible, hence they are evaporate quickly and can reach the stratosphere where ozone is available, thus causing ozone destruction (Sivasakthivel and Reddy, 2011). CFCs are highly destructive to the ozone layer as a result of their inability to be destroyed biologically and their relatively low solubility in water, thereby causing them to reach the stratosphere where they decompose to the reactive compounds of hydrogen chloride (HCl) and hydrogen fluoride (HF) (Turekian, 1996; Hegglin, 2018; Montzka *et al*., 2018; Prinn *et al.*, 2018; Ritchie and Roser, 2018; Elbeshbishy and Okoye, 2019; Langematz, 2019). Atmospheric researchers argue that the rate of this decomposition is much higher than previously thought so CFCs account for the main cause of ozone depletion (Montzka *et al.*, 2018; WMO, 2018; Harris *et al.*, 2019). Consequently, the CFCs can persist for eight to 12 years or more (Elbeshbishy and Okoye, 2019). At this rate, therefore, despite positive international steps to phase-out CFC usage, the atmosphere will only be able to naturally rid itself of ODS, at the earliest, in the middle of the 21st century (Cao *et al.*, 2016).

2.4.2.3 *Hydrochlorofluorocarbons (HCFCs)*

HCFCs are another, albeit less destructive, cause of ozone depletion; however, because they contain an extra hydrogen atom, they disintegrate in the lower atmosphere, so the bulk of their destructive chlorine does not reach the stratosphere. Hence, their adverse effect is less than that of CFCs (UNEP, 1996b). It is estimated that 94% of all HCFC production are from the Non-Article 5 parties (McCulloch and Midgley, 2015). According to the EPA (2010) and Prignon *et al.* (2019), HCFCs have less harmful effects on the ozone layer than CFCs and have over the years served as a substitute for CFCs. Wang *et al*. (2016) point out that HCFCs are being used in a few applications just as “transitional substances” since they are expected to be eliminated eventually because of their ozone depleting potency. Kloss *et al.* (2014) point out that HCFCs also contain chlorine, but their adverse impact on ozone is less severe owing to the fact that they contain hydrogen atoms. This makes it easier for hydroxyl radicals (OH) to remove them in the troposphere, hence they are unlikely to be transported into the stratosphere. They are also less persistent than CFCs, remaining in the atmosphere for roughly nine to 12 years (WMO, 2015; Li *et al.*, 2016). There is therefore general consensus that HCFCs are the better devil than CFCs, which tend to be more persistent in the atmosphere, thus having long-term consequences.

2.4.2.4 *Nitrogenous compounds*

Anwar *et al.* (2016) and Sharma (2019) revealed that traces of nitrogenous compounds released by human activities in small amounts like nitrogen dioxide (NO_2), nitrous oxide (N_2O) and nitric oxide (NO) are thought to be significantly responsible for depleting the ozone layer more than the contribution of CFCs. Ravishankara *et al*. (2009) add that if these synthetic compounds leak into the environment, they drift up into the stratosphere where chlorine (Cl) and bromine (Br) radicals freed by the action of ultraviolet radiation on their molecule act as catalysts, affecting the ozone layer at -78°, and lead to a comprehensive breakdown of ozone reducing it to oxygen molecules. Aggarwal *et al*. (2013) maintain that low temperatures and the increase in the level of bromine and chlorine gases in the stratosphere are reasons that prompt ozone layer depletion. The greenhouse power of N_2O is 300 times that of CO_2, and it accounts for 6 to 8% of the anthropogenic greenhouse effect the world over (Portmann *et al*., 2012; Li *et al.*, 2017). Li *et al.* (2017) and Langematz (2019) further add that N_2O has a very long lifespan of roughly 118 to 120 years, and its concentration in the atmosphere has been increasing at 0.2 to 0.3% annually over the past decade. Ballare *et al.* (2011) and Langematz (2019) cite N_2O as the leading ozone depleting emission, ahead of CFCs. The sources of N_2O are mainly plant life, including plant shoots exposed to sunlight (Ravishankara, *et al*., 2009), leaf tissues, conifers and foliage surfaces in higher temperatures (Hari *et al.*, 2003; Tang *et al.*, 2011). In fact, estimates are that boreal forests produce roughly the same quantities of NOx emissions globally as those from industrial and traffic sources (Tamm, 2012; Liu *et al.,* 2018).

2.4.2.5 *Global warming*

According to Anwar *et al.* (2016), Bias *et al.* (2018) and Sharma (2019), global warming also contributes to the depletion of the ozone layer. Anwar *et al.* (2016) contends that because of the greenhouse and global warming impact, the greater part of the heat is trapped in the lower stratosphere and as a result does not reach the troposphere. Consequently, the troposphere remains cold and, because ozone recovery requires maximum sunlight and heat, the ozone layer is depleted. On the other hand, Ashworth (2008) contends that any temperature changes in the stratosphere either promote or decrease stratospheric ozone destruction depending on the region. Ashworth (2008) adds that an increase in the concentrations of blended GHGs, which are required to cool the stratosphere, reduces the rate of gas stage ozone damage in a large part of the stratosphere and thus reduces stratospheric ozone destruction.

2.4.2.6 *Dichloromethane compounds*

Hossaini *et al.* (2017), Chipperfield *et al.* (2018) and Schuck *et al*., 2018) identified numerous human produced chlorocarbons (dichloromethane (CH_2Cl_2) not monitored by the MP as a cause of ozone depletion. Dichloromethane is a modern solvent mainly used as feedstock in the manufacturing of different chemicals, including solvents, paint removers and pharmaceuticals (Montzka *et al.,* 2011; Oram *et al.*, 2017; Feng *et al.*, 2018). Simmonds *et al*. (2006) and Claxton *et al.* (2019) state that dichloromethane is a fleeting substance, not at all like CFCs, which are relatively idle in the troposphere and have long atmospheric lifetimes. Carpenter *et al*. (2014) highlighted significant quantities of both naturally and anthropogenic short-lived ODSs that have been discovered in the lower stratosphere 15 to 18 kilometres high and are thought to play a negligible role in stratospheric ozone depletion due to their relatively short atmospheric lifetimes, normally six months, and therefore low atmospheric concentrations (Claxton *et al.,* 2019). What is worrying though is the fact that emissions of CH_2Cl_2 have doubled over the past few years (Perkins, 2017). Perkins (2017) calls dichloromethane a new threat that could slow down the recovery of the ozone layer over Antarctica by between five and 30 years or more. Dichloromethane occurs naturally in small quantities, meaning its increase over the past years, at the rate of 8% or 1 million metric tonnes annually between 2000 and 2012, can be attributed to human sources and activities (Hossaini *et al.,* 2017; Feng *et al.,* 2018; Claxton *et al.,* 2019).

In the presence of sunlight, CH_2Cl_2 disintegrates and releases chlorine atoms, which in turn disintegrate any ozone molecules they come into contact with. Initial evidence indicated that the impact of CH_2Cl_2 was minimal because it was thought to disintegrate before reaching the stratosphere where ozone exists, hence its exclusion from the 1987 MP (Department of Environment, Australia, 2016; Claxton *et al.,* 2019). It has recently been found, however, that this substance does in fact get transported to the lower levels of the stratosphere; hence it has ozone destroying potential. Still, if current emissions are held constant, the delay to the healing of the ozone layer would be roughly five years (Hossaini *et al.,* 2017; Claxton *et al.,* 2019). The Department of Environment, Australia (2016), added the following list of ODSs controlled by MP: halons, carbon tetrachloride, methyl chloroform, hydrobromofluorocarbons, methylbromid and bromochloromethane, and highlighted that the potency of these ODSs to destroy ozone is measured by their ODP.

2.5 The ozone depletion-climate change matrix and impacts to life and the environment

The literature is replete with various documented effects of ozone layer depletion. Norval *et al*. (2011), Griffin *et al*. (2019) and Langematz (2019) state that the immediate effect is the escalation of the harmful UV-B radiation with wavelengths ranging from 280 nm to 315 nm reaching the earth’s surface. Increased exposure of humans to UV-B radiation generally has detrimental effects on health, but shifts in human behaviour over the past 60 years have ameliorated these (Kundu *et al*., 2016; Sharma, 2019). Anwar *et al*. (2016) agree that depletion of the ozone layer has effects on animals, humans, plants and the environment. They see UV-B filtered through the ozone layer as imposing significant environmental stress. Since the ozone layer is a shield against hurtful UV-B radiation, any destruction to it could cause significant damage to the earth and life on earth (Bolaji and Huan, 2013). Kundu *et al*. (2016) commented that it is difficult to quantify the direct and indirect health and environmental effects of ozone depletion. Boucher (2010), however, explains that the ultimate amounts of UV-B that reach the earth's surface are moderated by intermediate influences like the amount of cloud cover, ozone residues in the troposphere ozone, as well as aerosols.

2.5.1 Climate change effects of ozone depletion

According to the UNEP (2010a), Aggarwal *et al*, (2013), Bias *et al*, (2015), Hassenzah *et al*, (2017) the ozone layer depletion causes warming of the earth and this is evidenced by the 5.5 °C increase in the atmospheric temperature by 2021. Ozone layer depletion leads to a decrease in ozone in the stratosphere and an increase in ozone present in the lower atmosphere as a result of anthropogenic bromine and chlorine containing gases having a cooling effect on the earth's surface (Maheshwari, 2013). The presence of ozone in the lower portions of the atmosphere is considered as a source of pollution and a greenhouse gas and it contributes to global warming and climate change (SARDC, 1994; Ashmore, 1995; Maheshwari, 2013; UNEP, 2015d; Bias *et al.,* 2018). The ozone layer depletion has streamed down effects such as those of global warming, which prompt the softening of polar ice, which in turn prompts rising sea levels and climatic changes far and wide, as well as a rise in atmospheric temperatures beyond normal levels (SARDC, 1994; UNEP, 2010a; Sivasakthivel and Reddy, 2011; Barnes *et al.,* 2019).

Aggarwal *et al*. (2013) assert that ozone depletion builds the force of UV-B radiation and leads to the average increment in ground level UV-B radiation. The sun transmits radiation over an extensive variety of UV-B radiation, with around 2% as high-vitality ultraviolet. Sivasakthivel and Reddy (2011) reported that the biggest abatements in ozone during the previous 15 years have been seen over Antarctica, basically every September and October when the ozone hole formes. Studies on the environmental effects of ozone depletion (UNEP, 2014a; Bais *et al.*, 2015; Bornman *et al.*, 2015; Barnes *et al.,* 2019) stress that ozone depletion significantly affects climate, resulting in effects on weather over great parts of the Southern Hemisphere, including changes in temperature and rainfall. Greater internal climatic variability caused by atmospheric ocean perturbations such as the North Atlantic Oscillation (NAO) and El Niño Southern Oscillation (ENSO) are now a reality (Meyssignac and Cazenave, 2012; Previdi and Polvani, 2014). This manifests as a general escalation in global mean surface temperature (GMST) by about 0.8 °C since 1900 (SARDC, 1994; Rowland, 2001), a significant reduction in ice in the

Arctic Sea (UNEP, 2017b), an increase in sea levels (Meyssignac and Cazenave, 2012), more intense and frequent droughts (EEAP, 2017; UNEP, 2017b), floods, heat waves, tornadoes and hurricanes (Venkataramanan and Smitha, 2011), and more wildfires (Robinson and Erickson, 2015). The Intergovernmental Panel on Climate Change (IPCC, 2007) and Bindoff *et al.* (2013) acknowledge that climate change is a function of numerous climate altering agents as well as random variability. There is general consensus that the significant global warming has primarily been an outcome of human activity and its attendant effects on the makeup of the atmosphere.

There is recent evidence by Friedlingstein *et al.* (2010) showing a steep escalation in fossil fuel-related carbon dioxide (CO_2) emissions during the 2000s. Findings from power sector in Pakistan suggest that CO_2 emissions will probably reach 277.9 MT in 2035 due to increase in demand for electricity (Lin and Raza, 2019). Other researchers, though, are more optimistic. Stolarski *et al*. (2010) and the UNEP (2014c), for example, see GHGs and ODS decreasing, in turn decreasing stratospheric temperature over the past several decades, assisting ozone recovery on the one hand while the concentration of GHGs continues to increase. However, they foresee that there will be a moderate to total recuperation of stratospheric ozone amid the centre third of the 21st century.

2.5.2 Ozone depletion effects on plants

The introduction to UV-B beams as a result of ozone depletion causes countless biological risks, for example variation in the physiological and developmental processes and the reduced growth and productivity of plants (Tundo and Zecchini, 2007; Maheshwari, 2013; Andersen *et al.*, 2018). Indirect harm caused by UV-B includes changes in the plant shape and conveyance of supplements inside the plant. These effects have serious ramifications for plant competitive balance, plant disease and biogeochemical cycles (UNEP, 2015d).

Aggarwal *et al.* (2013) and Bias *et al.* (2018) posit that there are countless effects of UV-B radiation on worldwide plant efficiency owing to the stratospheric ozone depletion that has been experienced. Past research (Basiouny, 1982) reports the loss of 50% crop plants in European nations attributable to UV-B radiation that penetrates the earth’s surface. Tundo and Zecchini (2007) highlight that UV-B radiation antagonistically influences the rate of photosynthesis in plants, causing diminished agribusiness opportunities. Ballaré *et al.* (2011) estimate loss of productivity resulting from UV-B conservatively at no more than 6%, which they attribute largely to the achievement of the MP in restricting ozone disruption since 1987. Ballaré *et al.* (2011), however, counsel caution in the application of this estimate owing to variations in plant vulnerability revealed by several studies (Basiouny, 1982; Tundo and Zecchini, 2007; Laposi *et al.*, 2009). Additionally, Newsham and Robinson (2009) and Searles *et al*. (2001) point out that what may look like insignificant short-term effects may in fact turn out to be significant in the long run. UV-B radiation also affects the fresh weight, height, dry weight and ash contents of plants which reflect the deleterious effects of UV-B on crop plants (Tundo and Zecchini, 2007).

Allen *et al*. (1998) explains that UV-B increases the evaporation rates through stomata and causes diminished soil moisture content, consequently, the development and growth of crops are affected. According to Laposi *et al.* (2009), Bornman *et al*. (2019) and Williamson *et al.* (2019), depletion of the ozone layer negatively influences the climate which affects crop yield because of plant damage and progress of different diseases. Other expert studies (Krizek *et al.*, 1998; Emberson *et al.*, 2018; Bornman *et al*., 2019) have reported that the greatest impact of ozone depletion is focused on the leaf production of plants. In a study by Searles *et al.* (2001), the results showed that development of leaves is limited by UV-B radiation, while leaf size and thickness is reduced and increased, respectively. Bornman and Vogelmann (1991) and Laposi *et al.* (2009) suggest that all these changes, together with the accumulation of waxes on the leaf surface, result in a reduction in the aggregate number of leaves produced.

UV-B short wave exposure results in deoxyribonucleic acid (DNA) damage. A study conducted by Shindell *et al.* (1998) on short wave UV-B exposed plants showed indications of acute DNA damage to the plants. Studies by Newsham and Robinson (2009) and the UNEP (2010a) revealed indications that the exposed plants showed the disturbance of biological macromolecules, including nucleic lipids, acids and proteins. The plants additionally indicated mutant arrangements that modify the development properties which hamper the ideal usage of the plant products (Maheshwari, 2013). However, Aggarwal *et al*. (2013) detailed the positive aspects of UV-B radiation, which assumes that it plays a vital role in the development of plant and animal species.

2.5.3 Ozone depletion effects on terrestrial and aquatic ecosystem

In addition to the direct effects of UV-B on plants, effects may also be indirect by causing changes to terrestrial and aquatic ecosystems (Maheshwari, 2013; Bias *et al.*, 2018). According to the UNEP (2010a), ozone depletion plays an essential role in the advancement of terrestrial plants by improving phenolic polymer digestion caused by UV-B. The UNEP (2015c) has reported results that revealed changes in terrestrial ecosystems in the Southern Hemisphere mainly as a result of the Antarctic ozone hole. The resultant changes in precipitation patterns were reported to be correlated with the ecosystem, for example increased tree development in eastern New Zealand and the expansion of agribusiness in South-eastern South America (UNEP, 2015c).

A decrease in phytoplankton generation in the peripheral ice zone because of increments in UV-B has been shown (Tundo and Zecchini, 2007; Maheshwari, 2013). Sivasakthivel and Reddy (2011) and Aggarwal *et al*. (2013) revealed that UV-B can also harm the early development stage of shrimp, fish, crab, amphibians and other animals, the most extreme impacts being reduced reproductive capacity and diminished larval development. Exposure to sunlight-based UV-B radiation appears to influence both orientation mechanisms and mortality rates in phytoplankton, resulting in decreased survival rates for these living organisms. Tundo and Zecchini (2007) and Williamson *et al.* (2019) highlight that the quantity of oxygen and food formed by plankton could be reduced by extreme UV-B exposure. Also, according to Ghose (2015), UV-B rays cause genetic disorders, have an impact on heredity and, in high concentrations, upset the balance of the marine ecosystem. In particular, fish, green algae and other life on the mainland are adversely affected. The impact is even worse on young cells and larvae of aquatic life, estimates of this being twenty-fold (*ibid.*).

2.5.4 Effect of ozone depletion on food availability

Ozone layer depletion also causes food shortages for humans. Scientific research over the past few years (McCulloch *et al.*, 2003; Robinson and Erickson, 2015; Andersen *et al.*, 2018) has revealed that the thinning of the ozone layer also results in lower crop yields and affects food production. UV-B radiation is disrupting a physiological and developmental process which is decreasing the productivity of crops (UNEP, 2015d). Avnery *et al*. (2011), in their research on global crop yield reductions since 2000 as a result of surface ozone exposure under optimistic and pessimistic scenarios of O_3 pollution for three crops, found interesting results. The global forecast yield loss of wheat for the year 2030 was found to be 5.4 to 26%, that for maize to be 7% and that of soybean to be 19%, while total global annual agricultural losses were forecast at US$17 to 35 billion. Avnery *et al*. (2011), as well as Bais *et al.* (2015), Bornman *et al.* (2015) and Newsham and Robinson (2009), conclude that the outcomes of their investigations point to the fact that global food insecurity will likely emerge as a result of increasing O_3 pollution, even using conservative estimates. This in turn will be linked to human health effects.

2.5.5 Effects of ozone depletion on structural materials

Expanded levels of sun-based UV-B radiation negatively affect manufactured polymers, naturally occurring biopolymers and some other materials of marketable interest (Sivasakthivel and Reddy, 2011). UV-B radiation accelerates the photo degradation rates of these materials subsequently restricting their lifetimes. Maheshwari (2013) adds that damage caused by UV-B ranges from loss of mechanical integrity to discoloration. According to the UNEP (2015b), the effects of sun-oriented UV radiation and climate change on the lifetime of polyvinyl chloride (PVC) building items are a cause for concern. Andrady *et al.* (2015), the UNEP (2017b) and the EEAP (2017) note that outdoor wood and plastics exposed to UV radiation, especially in high temperature zones, have significantly shorter life spans. In fact, the higher the proportion of UV-B radiation these materials are exposed to, the shorter their service lives (Bais *et al*., 2015). However, the precise impact of UV-B on materials shows geographic variations, as UV-B concentrations differ by latitude and altitude.

2.5.6 Effects of ozone depletion on skin

The incidence of skin tumours is escalating throughout the world and these have largely been attributed to humans' increased exposure to UV-B radiation because of ozone layer depletion (Ghose, 2015). It is estimated that 2-3 million cases of non-melanoma cancer occur globally every year with US constituting 30% (Narayanan *et al.*, 2010). Skin cancers of the non-melanoma type are common in the US (Gupta *et al.*, 2016). These include basal cell and squamous cell carcinomas, which have become more common over the last twenty years, particularly in body parts like the neck, hands, arms and head that are generally exposed to the sun. Most common among the cancers are three types: melanoma (the most perilous yet least frequent), squamous cell carcinoma (which advances and grows quickly into the skin) and the basal cell carcinoma (the minimum risk yet most broad) (Boucher, 2010; Padrik *et al.*, 2017).

Australia has the second highest rates of UV-B radiation-related melanoma cancers, with 56 new instances recorded every year for every 100 000 men. The corresponding figure for women is 43 in every 100 000 (Murtaza, 2015). Norval *et al.*'s (2011) estimates put the annual incidence at between five and 24 per 100 000 in Europe and the USA, with Coory *et al.* (2006) and Linos *et al.* (2009) estimating more than 70 per 100 000 in higher ambient UV-B radiation locales in New Zealand and Australia. The extent of the problem is such that even in areas where these cancers are not very prevalent, high incidence rates of up to 125 per 100 000 occur, for example among white men of non-Hispanic extraction aged over 65 in the USA. Women between the ages of 17 and 33 are the most vulnerable to melanoma in Australia (*ibid.*).

According to Coory *et al.* (2006) and Tian and Juan (2009), skin cancers are caused by human's exposure to UV-B radiation, which structurally alters biomolecules and thus leads to various skin diseases. Similarly, Pearce *et al.* (2003) and Garnett *et al.* (2016) maintain that ozone layer depletion results in skin cancer and sunburn. The opinions of these authors are realistic, as the skin is the part of the body most often exposed to ultraviolet B radiation. According to Anwar *et al*. (2016), there are two types of skin cancer, namely, melanoma and non-melanoma types. Melanoma, which is frequently fatal, is the most serious form of cancer, while the more common non-melanoma type is less fatal. Wargent and Jordan (2013) highlight that UV-B radiation additionally causes leukaemia and breast cancer. The skin cancers most common in humans, basal and squamous cell carcinomas, have also been traced to UV-B exposure (Dobson, 2005; Lucas *et al.*, 2015; Padrik *et al.*, 2017). A study by Tundo and Zecchini (2007) suggested that a reduction of 1% in the ozone layer would increase the UV-B radiation reaching the ground by 2%, in turn increasing carcinomas by an average of 5%. Similar figures were reported by Dobson (2005). The effects of these radiations are acute and chronic, for example skin redness, tanning and peeling, as well as photo keratitis, photo conjunctivitis and chemosis in the eyes (also known as swelling) (Murtaza, 2015).

Anwar *et al*. (2016) discovered that the chances of melanoma occurrence are linked to UV-B exposure; furthermore the survival rate of melanoma is lower in boys than in girls and melanoma is prevalent in thin-skinned people. To confirm the effects of UV-B radiation, Boniol *et al.* (2006), Lomas *et al.* (2012) and Bias *et al.* (2018) support the notion that there is a significantly higher number of instances of cancers in thin-skinned people and it is more prevalent in children than in adults. Epidemiological studies have indicated that young females are more vulnerable to non-melanoma skin carcinoma in lower limbs and there is five times more risk to the trunk region owing to sun bathing (Pearce *et al*, 2003; Lucas *et al*., 2015). Intermittent sun exposure and sunburn history have also been significantly linked to melanoma risk. The same observation was made between the dark-skinned populations of South Africa and Kenya with a sunburn history (Clairwood *et al.*, 2013; Nthumba *et al.*, 2013; Norval *et al*., 2014). It has also been suggested by Lucas *et al.* (2015) that darker skinned people diagnosed in the USA were susceptible to advanced cutaneous malignant melanoma (CMM). They, however, hypothesised that in the body sites that are not normally exposed to UV-B radiation, systemic UV-B effects were likely to be the cause as opposed to direct UV-B exposure (Agbai *et al.*, 2014).

Gandini *et al.* (2005) and Agredano *et al.* (2006) introduced another dimension, noting a direct correlation between melanoma incidence and air travel. These studies confirmed that thin-skinned people are at risk. Solar UV radiation exposure may cause photo ageing and skin cancer, yet it also starts the creation of vitamin D which is essential for human health (Clairwood *et al.*, 2013; UNEP, 2015d). Similarly, Boucher (2010) and Apalla *et al.* (2017) found that the white population in the UK is more susceptible to a pre-skin cancer called actinic keratosis, attributable to exposure to UV-B radiation. Karimkhani *et al.* (2015*)* reported that in the period 1982–2011 the prevalence rates for men was 1.5% and 6% for women in the UK. de Gruijl (1995) found it challenging to quantify the rate of skin cancer prevalence the world over because it seems this rate is expanding in many areas.

Norval *et al.* (2011) assert a positive link between exposure to ultraviolet B and certain forms of pterygium, cataract, pinguecula (conjunctiva degradation) and conjunctiva and cornea squamous cell carcinoma. Murtaza (2015) is equally convinced that protracted exposure of the eyes to UV-B radiation causes posterior and subscapular cataract. The 280 to 320 nm wavelength UV-B radiation is the culprit in the case of cataract development.

Undoubtedly, total personal UV-B exposure is a function of not only the intensity of ambient UV-B radiation, but also the duration of exposure to the sun and the total skin surface exposure. As UV-B is a poor penetrator of human tissue, the adverse health effects affect exposed surfaces and eyes (Lucas and Gies, 2011). Most blindness in this world emanates from cataracts. According to the UNEP (1994), cataract risk would escalate by 0.3 to 0.6% should there be a 1% decrease in ozone amounts. UV-B radiation produces oxidative agents which inflict severe harm on the lens and cornea of the eye (Christenson *et al.*, 2005). Furthermore, Wargent and Jordan (2013) claim that the cataract, blindness and photokeratitis are all are linked to UV-B rays. In addition to the conditions identified, Bolaji and Huan (2013) suggest that additional eye conditions like presbyopia can result from increased exposure to UV-B radiation.

2.5.7 Ozone depletion effects on human immunity

Another negative effect on human health of exposure to UV-B radiation is the weakening of the immune system (immunodeficiency) that produces antibodies and immunity cells, resulting in increased vulnerability to diseases (Tundo and Zecchini, 2007; Anwar *et al.*, 2016; Sivasakthivel and Reddy, 2011; Aggarwal 2013). Similarly, observations made by Lucas and Gies (2011) suggest that outdoor workers are more prone to their immune systems being compromised because of the duration, intensity and wavelength of the UV-B radiation exposure response. Immune suppression occurs as a result of the changes in skin photoreceptors and antigen presenting cells that are brought by UV radiation (UNEP, 2006; Anwar *et al.*, 2016). The compromise of the immune system through UV-B exposure not only occurs in humans. Experiments on animals indicate that UV-B radiation exposure decreases the immune response to infectious agents, skin cancers and other antigens (Maheshwari, 2013; UNEP, 2015c).

2.5.8 Other health effects of ozone depletion

Various studies have shown that initial effect of UV-B radiation targets external parts of the globe. However, not only the external parts are affected, as suggested by Lippmann (2009), who argued that ozone is entirely a secondary polluting agent formed by the complex photochemical reactions of hydrocarbons, nitrogen dioxide and sunlight, which also cause lung irritation through inhalation. Fears *et al.* (2002) and Langematz (2019) support the fact that an increase in surface UV-B results in increased tropospheric ozone depletion, which is a health risk as ozone has strong oxidant properties. Ozone is formed daily through these chemical processes and is more concentrated outside closed environments through nose inhalation, and is less concentrated indoors where the common sources are copying machines and electrostatic indoor sources causing nose and respiratory problems (Lippmann, 2009). Similarly, Sivasakthivel and Reddy (2011) and the EPA (2013) propose that ground level ozone is by and large perceived to be a wellbeing hazard, as ozone is poisonous because of its solid oxidant properties. Wargent and Jordan (2013) indicate that the risks are especially high among youngsters, elderly people and individuals experiencing respiratory problems.

2.6 **Global response to the environmental challenges**

The ozone layer depletion is an international issue, which does not recognise national borders. The best way to deal with it therefore is through concerted international action (Ghose, 2015; Petrescu *et al.*, 2018). In 1987, countries worldwide appended their signatures to the MP on substances that deplete the ozone layer (EPA, 2001; Kloss *et al.*, 2014). The MP is a legally binding document which called for signatories to scale down their use of CFCs and other ODSs. Its introduction was followed in 1990 and again in 1992 by amendments which accelerated the expected CFC phase-out date for Non-Article 5 nations to 1995 (Ghose, 2015; Petrescu *et al.*, 2018; WMO, 2018).

Prior to this international response, it is worthy of note that there had been a discussion on the subject of ozone depletion by chlorine radicals by two sets of pioneers, Stolarski and Cicerone (1974) and Molina and Rowland (1974). Their discovery was followed by efforts to reduce ODS emissions through suggested citizen action as well as various international regulations (Molina and Rowland, 1974; Velders *et al.*, 2012; WMO, 2018). The existing MP is the latest active response with the objective of preventing ozone layer depletion and has evolved over time.

2.6.1 Regional and national response to the Montreal Protocol and Kyoto Protocol

Responding to alarming statistics on ozone depletion, the MP succeeded the VC with the main agenda of decreasing and eliminating the production of CFCs (Velders *et al.*, 2007; UNEP, 2010c; Lucas and Gies, 2011; UNEP, 2014b; Petrescu *et al.*, 2018; Sharma, 2019). Its aim as a global treaty was to safeguard the ozone layer by gradually reducing and eventually ceasing the manufacture of many chemicals that contribute to the depletion of the ozone layer, as well as providing a mechanism for decreasing and ultimately stopping the global manufacture and usage of ODSs altogether. One of the key issues for introducing this protocol is cited in the UNEP (2015d) as being to put in place measures to safeguard the health of humans and the environment against the negative consequences emanating from or probably emanating from anthropogenic practices which change or may possibly change the ozone layer.

The UNEP (2004; 2010b) reported that there was minimal involvement of African countries in the late-eighties with only three countries, Egypt, Ghana and Kenya, having shown interest in signing the MP. One of the obvious reasons for the lack of African involvement is probably negative perceptions, given the context in which developing countries might have been operating which was characterised by slow innovation and development. The MP was established for the purposes of addressing ozone depletion in various ways which include the identification of chemical substances believed to potentially negatively affect the ozone layer; commitment by the Parties to systematically research the causes and effects of ozone depletion and to work cooperatively to control human activities known or believed to be contributors to any negative impacts (UNEP, 2014b; Montzka *et al*., 2018). The MP brought a paradigm shift to the global refrigeration and air conditioning (RAC) sector (Velders *et al.,* 2007). This sector was largely unregulated and fragmented prior to the control of ODSs through the MP (Seki, 2017). This clearly shows that the mandate of the parties under this agreement was to reduce the production and consumption of ODSs so as to reduce their abundance in the atmosphere.

The UNEP (2010a) and Yoshida (2018a) show that the negotiations succeeded despite some areas of disagreement among some parties. Countries in the Toronto Group, namely Canada, USA, Norway, Sudan, Finland and Australia promoted a freeze on manufacture and major reductions; the European Community (EC) was in favour of imposing a cap on manufacture but no reductions (Yoshida, 2018b). The Union of Soviet Socialist Republics (USSR) and Japan showed hesitance in relation to any cuts, the fear among developing countries was that any restrictive measures would hamper their development, the majority of industries were against reductions in CFC manufacture and usage, and there was disagreement over the form and the number of issues for inclusion in the Protocol (Yoshida, 2018a). China being the greatest producer of HCFC reduced its annual production capacity by 280 000 tonnes of ODS in 2017. Contrary to all these efforts some Chinese companies have been accused of continuing use of the prohibited CFC-11 (Xu and Stanway, 2018).

2.6.2 Montreal Protocol evolution: Protocols and Conventions

Since the Protocol has come into effect, the parties have reached agreement on a number of amendments. These amendments have seen an improvement in the response as well as the involvement of more parties (Gonzalez *et al.*, 2015). The following noteworthy amendments have been effected to date:

2.6.2.1 *Phasing out of production of halogenated CFCs*

The 1990 supplementary agreement to the MP (London Amendment) saw the same signatories commit to cease using CFCs and that of additional other chemical compounds with ODP by the end of 1995 (UNEP, 2001; Gonzalez *et al.*, 2015). One of the major highlights of the amendment was to speed up the phase-out of all identified ODSs. This amendment expanded the list of substances to be controlled to include carbon tetrachloride, fully halogenated CFCs, and methyl chloroform (Finas, 2003; Montzka *et al*., 2018; Petrescu *et al*., 2018). The amendment also resolved to eliminate the manufacture and usage of CFCs, carbon tetrachloride and halons by 2000 and of methyl chloroform by 2005 (UNEP, 2001; Gonzalez *et al.*, 2015). Trading in these substances was also banned particularly with non-signatory countries. In order to achieve the objectives a special fund was created with the aim of helping developing countries fulfil their obligations and a separate timetable was created for reductions and phase-out of ODS. Effectively, the amendment was finally in effect in 1992 after having been ratified by 163 countries (Finas, 2003; WMO, 2015).

2.6.2.2 *Acceleration of phasing out of ODSs*

The parties to the MP again amended the Protocol in Copenhagen in 1992 in order to accelerate the phasing out of ODS by the United States and other countries (Middlebrook and Tolbert, 2000; Gonzalez *et al.*, 2015). The Copenhagen amendment to the MP was mostly focused on the tightening of the timetable for the reduction of ODSs (Maheshwari, 2013). The Copenhagen Amendment provided for the complete phase-out of production and consumption of CFCs, carbon tetrachloride and methyl chloroform by the beginning of 1996 and of halons by the beginning of 1994 (Middlebrook and Tolbert, 2000; Rowland, 2001; Petrescu *et al.,* 2018). Methyl bromide and hydrobromofluorocarbons were included in the list of controlled substances and were to be phased out by developed countries by 1 January 1996. According to Wang *et al*. (2016), HCFCs which were developed as a substitute for CFCs were also added to the same list and it was obligatory that they be gradually phased out by 2030. According to the UNEP (2010b), the amendment took effect in 1994 and was ratified by 141 countries.

2.6.2.3 *Phase-out of methyl bromide and adjustment to HCFC phase-out schedule*

The Vienna Accord of 1995, as a treaty, initially agreed on a timetable that would frequently be subject to review as new evidence emerged on the impact of ODSs. Consequently, in 1995, 2010 was set by the Conference of the Parties to the MP as the date by which developed countries should have phased out the use of methyl bromide. The Vienna Accord furthermore amended the HCFC phase-out schedule slightly (United States Government, 2002; UNEP, 2012a).

2.6.2.4 *Ban on trade of controlled substances to non-parties of the Montreal Protocol*

According to the United States Government (2002), the Montreal Adjustment was effected in 1997 and agreed to include methyl bromide in the prohibition on trade in controlled substances with non-signatory countries. To prevent unlawful trade, the Montreal Adjustment also made it an obligation on all to put in place import and export licensing systems for all used, recycled, reclaimed and new controlled substances including methyl bromide (UNEP, 2010c; Petrescu *et al.,* 2018).

2.6.2.5 *Freeze and ban trade in HCFCs and bromochloromethane*

The Beijing Amendment of the MP, adopted in 1999, introduced production control measures and enacted limits on trade in HCFCs (UNEP, 2015b). The amendment also imposed a freeze and a ban on the trade in all HCFCs and bromochloromethane. The ban was imposed on the parties to the amendment, whilst also cutting across non-parties (UNEP, 2007). Middlebrook and Tolbert (2000) indicate that complete phase out of HCFCs was scheduled for 2020 in Non-Article 5 countries and 2040 in Article 5 countries. Wang *et al.* (2016) claim that both the consumption and production of transitional HCFCs have been frozen in both developed (Non-Article 5) and developing (Article 5) countries since 1996 and 2013 respectively.

2.6.2.6 *Phase-out of production and consumption of hydrofluorocarbons*

The MP has had a positive effect on the phase out of ODSs chiefly by replacing CFCs and HCFCs with HFCs in several areas such as foam blowing, aerosols, air conditioning, refrigeration and fire extinguishers. The high global warming potential (GWP) of HFCs replacing ODSs is a climate concern and is the reason behind the Kigali Amendment of the MP agreed in Kigali, Rwanda (Seki, 2017; Purohit *et al.*, 2018). The Kigali Amendment brought into existence a legally binding multilateral agreement to control the production and consumption of HFCs. The aim is to support climate friendly refrigerants and speed up innovation for sustainable technologies. Ultimately, the hoped for outcome is to support the long-run goals articulated in the Paris Agreement of limiting global temperature increases to well below 2 °C above pre-industrial levels (specifically 0.06 °C). This contrasts well with projected global temperature increases of up to 0.35 to 0.5 °C in the absence of HFC emission reduction measures (Xu *et al*., 2013; Velders *et al*., 2015).

The Kigali Amendment extended global regulation to control HFCs to regional and national levels (Velders *et al.*, 2015). According to Labacher (2017), the phase out was structured into three groups with different milestones. The grouping criteria used were the climate as well as the extent of development of the country. Similarly, Seki (2017) pointed out that the groups were in three categories despite noted differences in implementation dates and milestones. Seki (2017) further reported that HFC usage in developed countries will flatten out at 15% of the baseline in 2036, in 2047 for developing (Group 2) countries and at 20% in 2045 for Group 1 countries. Given the reports by Labacher (2017), the group's approach to phase-out strategy seemed to be optional. The bulk of HFC consumers and producers such as Brazil, Mexico, Argentina, Malaysia, South Korea, Indonesia, and Thailand all opted for the earlier schedule which was meant for Group 1. According to Seki (2017), many of these countries were subject to the provision of financial and technical support. According to Graziosi *et al.* (2017), the Kigali Amendment called for developed countries to have 2019 as the start date for phasing down of HFCs and for developing countries to freeze the same between 2024 and 2028.

The Kigali Amendment of October 2016 marked the 28th meeting of the signatories to the initial MP. The 197 signatories to the Kigali Amendment committed, worldwide, to significantly the lessen production and consumption of HFCs (Graziosi *et al.,* 2017). Seki (2017) reported that the measurable targets of the Kigali Amendment were to avoid emissions of HFCs by at least 70 billion tonnes of carbon dioxide equivalent (CO_2e) by 2050. The

Amendment opened up and created international markets with new technology that is climate and ozone friendly. It also encouraged a gradual phase down by all countries in their use and manufacture of HFCs using the innovative, effective and flexible approaches previously used by the MP before (Seki, 2017). Sandler (2017) highlight the date on which the Kigali Amendment will be effected as 1 January 2019 and it will address global warming with the objective of contributing considerably to the goals contained in the Paris Agreement, to continue efforts to restrict the average global temperature increase to 1.5 °C.

Seki (2017) noted that the Kigali Amendment was possibly by far the most significant contribution of the world thus far towards continuing to address global warming and at the same time dealing with ozone depletion. The cornerstone of the Kigali Amendment is anchored on achieving specific targets and adhering to timetables that will help in replacing HFCs with more environmentally friendly alternatives, as shown on Figure 2.2. Article 5 countries have been divided into two groups with the freezing of HFC consumption and production in 2024 and mitigation from 2029 onwards, while developed countries directly reduced targets from 2019 (Michaelowa *et al.*, 2018**)**. Financial resources were made available, in particular, to Article 5 countries that opted for faster phase-out timelines than required, motivated by the grave risks faced by the region owing to climate change.

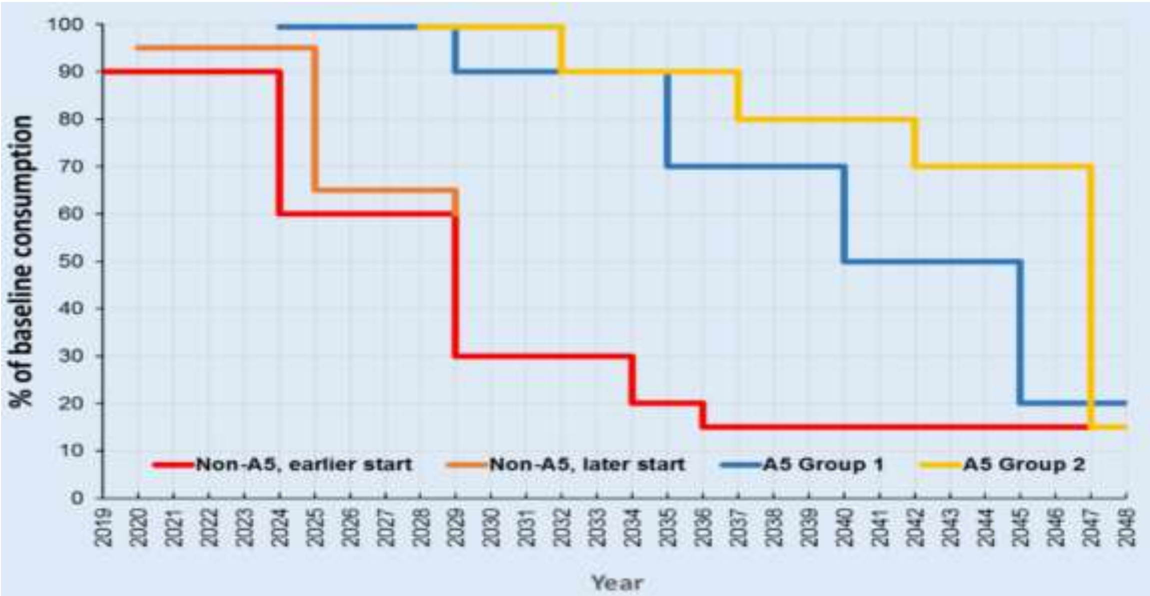


Figure 2.2: Kigali Amendment HFC phase-down schedules
Source: Michaelowa *et al.* (2018)

2.6.3 Montreal Protocol: the achievements

The MP and its amendments have produced notable achievements. The MP may be seen as a crucial landmark in dealing with global environmental problems and pushing the sustainable development agenda in the 1990s (Tsai and Chou, 2008; Egorova *et al.,* 2013*;* Fahey 2013). According to Montzka *et al.* (1996), action items that emanated from the protocol are authentic because they were guided by long-run measurements of a select few CFCs at remote ground stations plus measurements contained in balloons in the stratosphere. For this reason, the 1987 MP was a significant agreement which has substantially reduced global production, consumption and ODS emissions (WMO, 2007; UNEP, 2015b; Hossaini *et al*., 2017; Manatsa and Mukwada, 2019). According to Velders *et al.* (2012), Egorova *et al.* (2013) and the WMO (2018), apart from the reduction in emissions causing ozone layer depletion, the Protocol has also gone a long way in reducing climate change caused by GHGs. The successful implementation of the Protocol has since launched discourse on how to recover ozone in the second half of the 21st century.

Similarly, Chipperfield *et al.* (2015) reported that the MP significantly mitigated polar ozone loss. According to reported estimates, the Antarctic ozone hole would have grown 40% bigger by 2013 if the Protocol had not been implemented (Chipperfield *et al.,* 2015; WMO, 2015; NASA, 2018). Garcia *et al.* (2012) state unequivocally that without the MP, the stratospheric ozone layer would have been diminished to less than 100 DU worldwide by 2070. The progress of the Protocol, as seen against the situation as far back as 1987, has been significant as substantial reductions in the global anthropogenic emissions of ODS have been witnessed (WMO, 2007: Egorova *et al.*, 2013; Petrescu *et al.*, 2018).

An offshoot of the MP's effectiveness in reducing ODS has been the reduction in global warming (McKenzie *et al*., 2011; Haaland and Harness, 2018). This is because the greenhouse effect of the replacement substances advocated by the Protocol falls below that of the CFCs replaced (GWP = 1 for CO_2). For example, two of the original CFCs, CFC-11 and CFC-12, have GWPs of 3800 and 8100, respectively; their replacement, HCFC-22, has a GWP of 1780 (IPCC, 2007: Haaland and Harness, 2018).

In fact, comparatively speaking, the MP alone has already registered climatic protection that surpasses the reduction target of phase 1 of the KP (ending 2012), for instance from the point of view of the reduction in GHG emissions (Velders *et al.*, 2012). From another perspective, estimates are that the reduction in temperature on the ground following the phase-out of ODSs is approximately equal to the temperature increase resulting from more GHG emissions, at least through the initial two 21st century decades (Velders *et al.*, 2007; WMO, 2015). Thus, the MP has truly managed to reduce the concentrations of chlorine in the atmosphere, as well as mitigating global warming.

Other studies (Newman *et al*., 2009; Velders *et al*., 2009; Bias *et al.*, 2015; WMO, 2018) have reported similar success of the MP from the perspective of the "world avoided" if the MP had not been ratified. As its successful ratification prevented the steady escalation in the atmospheric load of ODSs, serious ozone depletion and consequent increase in UV-B were obviated (Mader *et al.*, 2010; Langematz, 2019). The UNEP (2010b) views the MP as one of the best instances of true global cooperation in dealing with a global environmental problem. Ozone depletion today continues to be an unresolved environmental issue, although there is evidence of ozone recovery (Chipperfield *et al.*, 2015; Solomon *et al*., 2016; Langematz, 2019). This is obviously due to the controls imposed on the manufacture of ODSs as part of the 1987 MP and its amendments.

However, there are countries such as the United States that have led efforts to protect the ozone layer but have been critics of the Protocol (Barnes *et al.*, 2018). Despite their criticism, they are now involved and acknowledge that the efforts of the global environmental endeavour would work to safeguard our public health (UNEP, 2010b). The MP, as well as national regulations, have seen significant reductions in the manufacture, consumption, emissions and observed concentrations of CFC-11, CFC-12, methyl chloroform, and several other ODSs in the atmosphere (WMO 2007). The Protocol also authorised the Conference of Parties to adjust the schedule of reduction in the manufacture and use of the controlled substances without referring to the State Parties for ratification (UNEP, 2005; WMO, 2007; UNEP, 2012a). This is good progress in that not only does the Conference of Parties monitor progress but also seems to have the power to suggest and action their plans. In addition, the Protocol authorised the conference to recommend additional chemicals to be added to the list of controlled substances, as well as the production and use phase-out schedules to be applied (EPA, 2001; UNEP, 2015b).

Owing to the general compliance with the Protocol and its Amendments and, significantly, as industries develop ozone friendly alternates for the controlled chemicals, the total global collection of ODSs has abated and is decreasing (WMO, 2011; Al-Awad *et al*., 2018). The successes of the Protocol have gone to the extent of becoming a milestone recognised by the introduction of Ozone Day, which is celebrated internationally on 16 September (Seki, 2017). The Protocol committee has not disappointed in terms of funding the initiatives of the plan. The participating member states have been adequately funded to implement the response to ozone depletion (Mogola, 2008; Al-Awad *et al.*, 2018). Additionally, in the past 19 years, the MP Multilateral Fund has assisted nations in capacity building and networking among policy makers, customs officials and others (Andersen, 2015; Canan *et al.*, 2015; UNEP, 2018b). Among the Article 5 countries, Afghanistan received US$767 384 for the period 2011-2020, Botswana and South Africa received US$616 000 and US $6 533 556 respectively for the period 2012-2020 (UNEP, 2020). Through the fund, developing countries have been able to transfer essential technologies which have seen them leapfrog to new, energy-efficient technologies (hydrocarbons and ammonia) and take part in the global export of their wares (UNEP, 2010c; Fahey, 2013; Ghose, 2015).

In addition to the positive effects on stratospheric ozone and surface UV-B radiation, the MP has also reduced the negative effects of worsening tropical cyclones. This is due to the double ozone depleting and greenhouse properties of most ODSs restricted under the MP since late in the 1990s (WMO, 2015). The result has been the prevention of a further temperature increase over the sea surface, which greatly influences the intensity of tropical cyclones. Polvani *et al*. (2016) have demonstrated that, had the MP not been there, tropical cyclones would have been three times more intense by the year 2065. This has, in turn, greatly reduced cyclone-related damage, saving the world in the range of tens to hundreds of billions of US dollars (EEAP, 2017; Seki, 2017).

Overall, therefore, the MP has positively reduced the attendant effects of increases in the content of the main GHGs (i.e. CO_2, CH_4 and N_2O). The GHG reductions are expected to taper off in the future, however, so the long-run climatic impacts of the main GHGs may actually speed up in the future. It is also worrying that the stratospheric content of the replacement HFCs is increasing rapidly (Velders *et al.*, 2009; 2015; Fernando *et al.*, 2019). The WHO (2015) and Bias *et al.* (2015), on the other hand, stress the continued success of the adjusted and amended MP in decreasing emissions and atmospheric abundances of most controlled ODSs, and in fact call it the most effective environmental treaty ever, with ODS concentrations on the decline and ozone deemed to be on a positive recovery trajectory. Karentz (2008), Velders *et al.* (2015) and Fernando *et al.* (2019) add that the global compliance with MP on

ODSs has positively restricted emission of ODSs, and recovery of the ozone layer to the pre-1980 situation is expected in 100 years to come.

However, uncertainties still remain about the future (McKenzie *et al.*, 2011). These largely arise from interactions with climate change. Uncertainty also revolves around the political will to ensure compliance with the MP, possible unexpected volcanic emissions, and gaps and new discoveries in our comprehension of the climatic procedures included. The exact quantifiable contribution of bromine compound to the depletion of ozone in the lower stratosphere is still not known. To add to that, bigger quantities of ODSs are now believed to be held in current storage banks than hitherto estimated and the majority of these may in due course find their way into the atmosphere, further perpetuating ozone depletion. Daniel *et al.* (2007) project that anthropogenic oxide of nitrogen will most likely assume a more important role in ozone depletion in the future as atmospheric chlorine content declines. In addition, the recently estimated role of N_2O (a greenhouse gas emanating from soils) is anticipated to be major by the mid-21st century (Ravishankara *et al.*, 2009; Velders *et al.*, 2015).

Therefore, historical data and trends thus far, while showing a positive trajectory, do not guarantee future success. The future remains uncertain, and the climate change and UV-B threat headaches of the international community are far from over. The international cooperation structured around the MP no doubt has been shown to be an effective response, but probably more monitoring, closure of knowledge gaps and adjustments will be needed to remain on top of the situation. Also, it is difficult to establish the success of the MP because of information gaps and the temptation for member countries to report favourably about themselves.

2.7 **Gases controlled by the Montreal Protocol**

According to Rowland (2001), CFCs were primarily responsible for significant ozone losses resulting in the development of the Antarctic ozone hole. Labacher (2017) also agrees that most ozone depletion attributable to human activities is primarily due to CFCs. Because of their high ODP, CFCs have been phased out through the MP and HCFCs were developed to replace them. The UNEP (2012a), Andersen *et al.* (2018) and Wilmouth *et al.* (2018) identified HCFCs as the other cause of ozone depletion, which are less destructive than CFCs and have served as a substitute of CFCs. HCFC-22 remains the refrigerant that is currently posing the most significant threat to the ozone layer. Literature here is focused mainly on HCFC-22 among the HCFCs, since it is the main focus of the study.

2.7.1 Chlorofluorocarbons and hydrochlorofluorocarbons

Chlorofluorocarbons are anthropogenic compounds comprising fluorine and chlorine and are used as refrigerants, cleaning solvents and blowing agents. Chlorine used in this gas has high potency to destroy the stratospheric ozone. As a result of their high ODP, CFCs have been phased-out through the MP and HCFCs were developed to replace them. Middlebrook and Tolbert (2000) and Barnes *et al.* (2018) noted that HCFCs were developed to temporarily replace CFCs and also contain chlorine, which is a potential threat to the ozone layer. Wan *et al*. (2011) highlighted that the imminent threat of HCFCs to ozone depletion is not as serious as CFCs. The reaction of HCFCs with hydroxyl radical (OH) in the troposphere is quick and most HCFCs disintegrate before reaching the stratosphere intact, unlike the CFCs, as a result they are safer than CFCs.

First used in the 1940s, HCFCs, also classified as ODSs, are controlled under the MP as temporary alternatives for the more ozone degrading CFCs, with a target of eventually phasing them out of production and consumption. Specifically, this was through the 1992 MP l Amendment (Simmonds *et al.*, 2017). These have the same applications as CFCs, namely, in refrigeration and air conditioning, as cleaning solvents and in foam blowing. By 2006, the use of HCFCs was deemed to be expanding rapidly and posing a threat to ozone repair and climate change mitigation efforts (Kaniaru *et al*, 2008). In other words, they have stratospheric ODP or GWP (Fang *et al.*, 2012b). As a result, an amendment was made to the MP in 2007, to try and speed up the phase out of massive uses of HCFCs in both developed and developing countries (Simmonds *et al.*, 2017).

HCFCs have greenhouse effects and high potential for global warming, although Graziosi *et al*. (2015) and WMO (2015) put the ozone depleting power of HCFC-22 (0.04 ODP) at around 20 times less than that of CFC-12 (0.82 ODP). Even though their threat to the destruction of the ozone layer is low, their mass production poses a significant threat of damage to the ozone layer (Wan *et al.*, 2011; Barnes *et al.*, 2018). The UNEP (2010c) classified CFCs and HCFCs as substances that are both powerful ODSs as well as super GHGs. Although reducing CFCs will prevent further destruction of the ozone layer, replacement with HCFCs, which are very potent global warming substances, is not a lasting solution. It is clear that the reduction of CFCs and replacement with the mass production of HCFCs detracts from the positive effects of controlling other ODSs. Although HCFCs were considered as substitutes for CFCs under the MP, their production and consumption were frozen in developed countries in 1996 and in developing countries in 2013 (Wang *et al.,* 2016; Barnes *et al.,* 2018).

2.7.2 Chlorodifluoromethane

Chlorodifluoromethane is a purely anthropogenic halocarbon compound called HCFC-22 or R-22. It has the chemical formula $CHClF_2$, and is a hydrochlorofluorocarbon (HCFC) (Forterms-Cheiney *et al*., 2013; Ng and Chow, 2014; Kalla *et al.*, 2018). HCFC-22 is one of the most popular refrigerants used in cooling systems and emits HFC-23 as by-product when manufactured (Kaniaru *et al*., 2008).

The downside to this widely used refrigerant, commercially used since the 1930s, is that it destroys ozone in the stratosphere (Xiang *et al.*, 2014; Harrison, 2016). Chlorine and fluorine present in HCFC-22 have the ability to deplete the ozone layer leading to the greenhouse effect as presented by the chemical equation $2CHClF_2 + 2O_3 = 2CO_2 + Cl_2O + 4F + H_2O$ (McCulloch *et al.,* 2006; Montzka *et al.,* 2011; Xiang *et al.,* 2014).

According to Montzka *et al*. (2011) and Kalla *et al.* (2018), major uses of HCFC-22 are for extruded polystyrene foam used in industry, commercial refrigeration and air conditioning. Miller *et al.* (2010) also noted chlorodifluoromethane use as feedstock in fluoropolymer manufacturer. HCFC-22 as a refrigerant is used mainly in residential air conditioners, refrigerators and freezers, as well as both commercial and industrial refrigeration (Wan *et al.*, 2011; Wang *et al.,* 2016). Yang and Wu (2013) add that HCFC-22 is widely applied in a diversity of refrigeration and air-conditioning equipment ranging from chillers, freezers, retail food refrigerators, cold storage warehouses, transport refrigeration, air/water/ground/source heat pumps, industrial process refrigeration and in refrigerant blends R502, R409A, R401A and R402A.

Researchers Harris *et al*. (2014) and Chirkov *et al.* (2016) state that HCFC-22 was first used in the 1950s. Since then manufacture and use thereof have gone up. It has also been used as a transitional substitute for a number of CFCs, less abundant only than the anthropogenic halocarbons CFC-12 and CFC-11. The ODP of HCFC-22 is 0.04 (Daniel *et al*., 2011) and it has a 1780 GWP, which is relatively high. The atmospheric lifetime is 12 years (UNEP, 2014b; WMO, 2015; Li *et al.,* 2016). This is consistent with Harris *et al*. (2014), who asserted that

HCFC-22 is at the top of the table in abundance in the atmosphere, with a 0.034 ODP and an atmospheric lifespan of 11.9 years. It also has high greenhouse effects, with a 100-year GWP of 1780 and its emissions greatly contribute to global warming (Zhao *et al.*, 2015). Anthropogenic emissions are the chief sources of HCFC-22 from its propellant and refrigerant uses. According to Yang and Wu (2013) and the UNEP (2010c), HCFC-22 has chlorine elements and possesses a slight ODP of 0.04 and a large GWP of 1790. Moore and Remedios (2007) suggested that this gas can be removed from the atmosphere by photolysis when it reacts with the hydroxyl radical OH radical and state that its chemical lifetime is 161 years, ODP 0.05, GWP 1780 and it has a lifetime in the atmosphere of 12 years.

Montzka *et al*. (2011) put the atmospheric lifetime of HCFCs at approximately 11.9 years. The GWP measures the relative abilities of different gases to raise global temperatures. A high GWP value reflects the greater ability of the gas to warm the earth in comparison with carbon dioxide (Stratosphere-Troposphere Processes and their Role in Climate (SPARC), 2013; Zhao *et al.*, 2015). In one study, Oruc *et al.* (2016) noted a slightly different HCFC-22 GWP of 1600 and ODP of 0.055.

Kloss *et al.* (2014) and Langematz (2019) defined the ODP of a substance as the measure of how detrimental on an emission mass basis a compound potentially is to the ozone layer, in comparison to an equivalent mass of CFC-11 emitted. Kloss *et al.* (2014) further define the GWP as the ability of a GHG to retain atmospheric heat in comparison to the capacity of carbon dioxide (CO_2) on a mass emitted basis. The GWP is a function of the radioactive properties and the length of persistence of the substance in the atmosphere. As a rule, the majority of CFCs rank high on ODP and GWP.

Harrison (2016) points out that lots of work continues in tracking HCFC-22 concentrations in the atmosphere and indications are that these continue to increase. Emissions have surged between 1995 and 2009 from Article 5 countries in Asia like India and China (Saikawa *et al*., 2012). These were a partial setback to the developed world’s efforts to phase-out the use and manufacture of HCFC-22 (Harrison, 2016). In situ, ground-based Advanced Global Atmospheric Gases Experiment (AGAGE) estimations, for instance, show that the tropospheric content of HCFC-22 went up from 191.8 ppt to 214.2 ppt to 219.8 ppt in 2008, 2011 and 2012 respectively (Carpenter *et al.*, 2014). The growth rate from 2011–2012 was 2.6% yr^{-1}. On a positive note though, there are signs that HCFC-22 emissions have plateaued since 2008 at approximately 370Gg yr^{-1} and it is hoped that these HCFC emissions will go down in the coming decade (Carpenter *et al.*, 2014).

The UNEP (2012a) described HCFC-22 as an interim substitute for CFCs and the cut-off dates for its use, as per the MP, are 2030 for Non-Article 5 and 2040 for Article 5 countries. However, recently, increasing evidence shows rapid growth in HCFC-22 use and manufacture (Yang and Wu, 2013). HCFC-22 has played a pivotal role in eliminating CFCs in the last fifty years. However, it too has a high GWP, and since moves are already underway to phase HCFC-22 out, as per the MP in both Article 5 and Non-Article 5 nations post 2013, stakeholders seek more accurate estimates of global and regional emissions (Saikawa *et al.*, 2012). HCFC-22 has become topical owing to its adverse effects on the ozone layer which contribute to climate change (Ramayia, 2012; Graziosi *et al*., 2015). The phase out of HCFC-22 has increased the demand for substitutes for HCFCs (WMO, 2015: Velders *et al.*, 2015; Wang *et al.*, 2016; Li *et al.*, 2016).

2.8 **Emission and consumption of HCFC-22**

Emission measurements have been done globally, nationally and even regionally in order to establish how much halocarbon is emitted annually and to monitor the shifts occurring during the phase-out process (Fang *et al.*, 2012a; Wang *et al.*, 2016). The adage “what does not get measured cannot be controlled” justifies the relevance of reviewing literature centred on the measurement of the emissions and consumption of HCFC-22. Kloss *et al.* (2014) point out that since HCFC-22 has the capacity to degrade the protective layer and affect radiative force, it is of paramount importance to verify the existence, concentration and patterns of emission of these substances in the stratosphere. Only then can their impact on the environment be quantified and uncertainties about the future reduced. Velders *et al.* (2007) opine that in order to verify the effectiveness of the global response to ozone layer depletion and climate change under the MP, it is crucial to estimate emissions of HCFC-22 from atmospheric observations.

2.8.1 Sources of HCFC-22 emissions

HCFC-22 on its own is safe when used in a particular product without any exposure to or emission into the atmosphere. The challenge arises where there is poor handling leading to various HCFC-22 exposures in the atmosphere. There are different ways in which HCFC-22 emission into the atmosphere may occur. The most obvious one is cited by Graziosi *et al.* (2015), who suggest that atmospheric emissions partially happen from gas-filled systems or products. Some of the exposure occurs at the stage of maintenance, but could also result from accidental damage or, if the material in the remaining equipment has not been captured and destroyed, at the stage of removal of equipment from service.

Xiang *et al.* (2014) alluded to emission as a result of seasonal variation. Piloted refrigerant leakage studies (Saikawa *et al.*, 2012) suggest neither the regular leaks nor the instant release from the breakdown of the air conditioning system vary with the seasons. On the contrary, according to Graziosi *et al.* (2015), there are indications in some regional atmospheric studies that there could be seasonal variations in HCFC-22 emissions as a result of changes in refrigerator and air conditioner use with weather. There are clearly knowledge gaps in respect of the drivers of atmospheric release. Saikawa *et al.* (2012) and Harris *et al.* (2019) agree that HCFC-22 is released into the atmosphere through production losses and through leakage during the use of commercial products, and there are no known natural emission sources.

It would seem that seasonal variation in the emissions in the past has not been closely monitored enough (Graziosi *et al.*, 2015; Say *et al*., 2019). Studies into refrigerant leakage seem to point to the non-existence of a seasonal linkage between the gradual leaks (regular emissions) and the immediate release resulting from the opening of the conditioning systems (Schwarz and Harnisch, 2003). Some studies, however, do indicate a seasonal relationship between the seasons and HCFC-22 emissions owing to weather induced changes in refrigerator and air conditioner usage (Zhang *et al*., 2010). Ultimately, Fortems-Cheiney *et al.* (2013) and Xiang *et al.* (2014) indicate that there are clearly knowledge gaps in relation to the processes that drive the atmospheric release of HCFC-22 and control strategies.

As human innovation continues to proliferate, including in the area of equipment that runs on HCFC-22, emission of HCFC-22 continues to escalate. Similarly, HCFC-22 has been used extensively in air conditioning and refrigerating equipment which, through one or the other, result in the invariable release of ODS into the atmosphere. According to Oruc *et al.* (2016), the popular reasons that lead to emission include breakdown of products or machinery and/or translocation. The residential air conditioner industry annually consumes about 60 000 tonnes of HCFC-22, making it the largest consumption sector (UNEP, 2011b; Wan *et al*., 2011; Wang *et al*., 2016). Developing countries still allow the sale of the new HCFC-22-utilising air conditioners and HCFC-22 is present in more than a million devices and products (Oruc *et al.,* 2016).

2.8.2 Global consumption and emission of HCFC-22

According to the definitions of the MP, consumption refers to a party's total manufacture and imports less exports of HCFC-22 (UNEP, 2011b). The past decade has seen demand for HCFC-22 steadily increasing. Prior to the accelerated agreement on HCFC-22 phase-out, growth in HCFC consumption was predicted between 2005 and 2015, with a forecasted increase of between 5 and 10% per annum (UNEP, 2011b). Despite the cap on global manufacture and use of HCFCs in developed countries in 2013, use of HCFC-22 has continued to increase significantly (Montzka *et al*., 2009), with full phase-out of these ODSs only due in 2040. Currently, though, there are signs that this growth in HCFC usage is slowing down. The rate of decrease was in fact 54% from 2007 to 2015, which was in alignment with the 2004 maximum manufacture and usage and reduction targets of 75% by 2010 and 90% by 2015 for developing countries. Simmonds *et al*. (2017) and Andersen *et al.* (2018) support the assertion that the MP and its subsequent amendments have effectively slowed down the concentration of HCFCs in the atmosphere. From another perspective, though, HCFC-22 alone accounted for an approximate 14% change in climate than the four combined HFCs in the period 2011-2015, putatively owing to the fact that HCFC-22 continues to be used in existing refrigeration equipment, perpetuating leaking banks. Of all HCFC global emissions, HCFC-22 accounts for approximately 79%.

HCFC-22 emissions are regularly measured using grab sampling techniques in three global ground-based networks and at a number of other sites around the world (O'Doherty *et al.,* 2004; Yokouchi *et al.,* 2006; Stemmler *et al.,* 2007). Results from all three networks show that in 2008, the HCFC-22 global mean surface mixing ratio was 188-192 ppt, with an annual growth rate of 8.0 ± 0.5 ppt yr^{-1} (4.3 ± 0.3% yr^{-1}) during 2007-2008. O'Doherty *et al*. (2004) reported an increase of about 60% greater than the mean rate of change during 1992-2004. Montzka *et al*. (2009) showed that HCFC-22 measurements continued to increase during 2005-2008. These findings were affirmed by Saikawa *et al.* (2012) in regard to the "bottom-up" and "top-down" estimates.

Fortems-Cheiney *et al.*'s (2013) findings on global HCFC-22 emissions using an inverse model indicated an increase from 182 ± 11 Gg yr^{-1} in 1995 to 410 ± 9 Gg yr^{-1} in 2009. Saikawa *et al.*'s (2012) corresponding figures for HCFC-22 emissions were 186 Gg yr^{-1} in 1995, 295 Gg yr^{-1} in 2005, and 397 Gg yr^{-1} in 2009. This represents an average accelerated growth rate in global emissions from 10.9 Gg yr^{-1} in 1995–2005 to 22 Gg yr^{-1} in 2005–2009. Most of this growth in HCFC-22 emissions emanated from Asia (Saikawa *et al*., 2012; Fortems-Cheiney *et al*., 2013) and China (Stohl *et al*., 2010; Li *et al*., 2016). The first atmospheric measurement of HCFC-22 in 2017 came from the Cape Point observatory (CPT) in south-western South Africa (SWSA), giving an estimated baseline atmospheric growth rate of 8.36 ppt yr^{-1}. SA's HCFC-22 emissions were estimated to be 3.0 Gg yr^{-1} (Kuyper *et al.,* 2019).Emissions of HCFC-22 at global level, extracted from the AGAGE box model (based on atmospheric data), went up from 23 435 Gg yr^{-1} in 1995, peaking at 38 345 Gg yr^{-1} in 2010, an increase of approximately 10 Gg yr^{-1}. However, there has been a decline in global HCFC-22 emissions since 2010, by 6.6% to 36 155 Gg yr^{-1} in 2015 (Simmonds *et al*., 2017).

However, for the same period 2005-2009, there was no substantial increase or reduction in emissions of HCFC-22 in respect of developing countries, according to regional inversion results (Simmonds *et al.,* 2017). Graziosi *et al.* (2015) also reported that consumption and production of HCFC-22 have shown an upward trend in the last 60 years, with Article 2 countries accounting for the bulk of the last decade's global increases. Graziosi *et al.* (2015) further found that in 2003, the maximum emissions over the entire domain was 38.2 ± 4.7 Gg yr^{1}, with a minimum of 12.1 ± 2.0 Gg yr^{1}) occurring in 2012. With the exception of secondary maxima in 2008 and 2010, these years were also characterised by a constant decrease in emissions. These observed regional emission decreases notwithstanding, measurements done in the period 2002-2012 at the two European stations showed an average increase of 7.0 ppt year, thanks to developing countries (Graziosi *et al.,* 2015).

Stohl *et al.* (2009) concur with studies that suggest an estimated increase in global emissions measured using "bottom-up" and "top-down" estimates. Stohl *et al.* (2009) further reported an increase in emissions of HCFC-22 between 1995 and 2009, with the increase or reduction from 2005 to 2009 being insignificant in developed countries. It may thus be concluded that there is obviously a net effect increase in emissions resulting from higher estimates from developed countries that manufacture, use and export gas and products containing HCFC-22. The results of various studies using different estimation techniques and methodology reveal that there is an increase in emission post-2005 despite the major differences in the percentage increases (Montzka *et al*., 2009; Saikawa *et al.,* 2012). Such measurement methods have resulted in capturing the attention of a greater part of the international committee to consider the ozone depletion as a major global catastrophe.

2.8.3 Consumption and emission of HCFC-22 in developed countries

One of the major producers of HCFC-22 is the USA, which has three HCFC-22 plants and supplies roughly 50% of all HCFC-22 used in the developed world. The European Union (EU) is home to ten HCFC-22 manufacturing plants, all capable of producing 184 000 metric tonnes/year; actual production hovers around this figure and is declining slowly (UNEP, 2002). Another huge producer of HCFC-22 is Japan, the production of which, in 2001, amounted to 88 000 metric tonnes accounted for by four manufacturers. Signs are that the manufacture of HCFC-22 is escalating in China and India, with 19 HCFC-22 producers in the former country capable of producing 200 000 metric tonnes (production in 2003 was actually 177 000 metric tonnes), and major ones in the latter, whose production expanded from 4000 tonnes in 1992 to 17 000 in 2002 (UNEP, 2002; 2003). Other countries for which data are available are Korea and Russia. Their production levels have been stable at 3000 and 5000 tonnes/year in Korea and a decline from over 4000 tonnes/year to under 1000 from 1996 to 1998 in Russia (UNEP, 2003).

According to the UNEP (2010c), exports of HCFC-22 from Europe totalled 18 862 MT in 2009. This shows that while its net consumption could be lowered by exports, the consequence still remains the same because it is still the same ozone that suffers from extensive use and emission. Inventory-based, “bottom-up” estimate methodology adopted by Wan *et al.* (2009) suggests that HCFC-22 emissions increased from 34 to 69 Gg yr^{-1} during the period 2004–2009 or 12 to 20% of total global emissions during these years. Studies (Millet *et al.*, 2009; Xiang *et al.*, 2014) showed lesser HCFC-22 emissions in the US and greater emissions in Australia, Europe and Asia.

According to Keller *et al*. (2012), measurements in 1998 showed that HCFC-22 varied in atmospheric concentration by about 0.000 21–0.000 28 ppm; concentrations in the northern hemisphere surpassed those in the southern hemisphere, 2009 atmospheric observations of

HCFC-22 concentrations were around 0.000 085–0.000 17 ppm. This sharp increase shows the significant threat posed by HCFC-22 to the ozone layer. Experts (Keller *et al*., 2012; Yang and Wu, 2013; Ogunniran, 2018; Schuck *et al.,* 2018) have estimated that without efficient control, HCFC-22 manufacture and usage could increase twofold by 2015, exacerbating the twin problems of climate change and ozone depletion.

Purohit and Hoglund-Isaksson (2017) highlighted that the market production of HCFC-22 in China increased from 106 kt in 2001 to 269 kt in 2005 with annual average growth of 26.2%. HCFC-22 in China accounted for a 23% emission across the globe in 2008 (Kim *et al.,* 2010; Fang *et al.,* 2012b). China is reported to be the world's biggest HCFC-22 consumer, producer and exporter (UNEP 2011a; Fang *et al*., 2012b).

Domestic consumption of HCFC-22 has mainly been a function of the increase in the manufacture of air conditioning equipment for domestic use. In 2006, China was manufacturing over 65 million units of household air conditioning units annually, the bulk of which were HCFC dependent. China is responsible for 80% of all HCFC production (UNEP 2011b; Wan *et al.,* 2011; Wang *et al.,* 2016). In compliance with the MP, China ceased HCFC-22 consumption in 2013. The reference baseline was the 2009–2010 level average, with reductions of 10%, 35%, 67.5% and 97.5% targeted by 2015, 2020, 2025 and 2030 respectively (Wan *et al*., 2011; Fang *et al.,* 2016). Starting in 2000, the world's biggest manufacturer of residential air conditioners is China, which produces 230 billion units per year, representing 75% of global production (Fang *et al.,* 2016). This is consistent with Wu *et al.*'s (2014) assertion that air conditioners were the biggest source of HCFC-22, with 2015 production figures at approximately 600 kt of HCFC-22 for all uses in China (Oram, 2017). The industrial and commercial refrigeration subsectors accounted for 14% of all HCFC-22 emissions and the XPS foam subsector, 2% (*ibid.*).

2.8.4 Consumption and emission of HCFC-22 in developing countries

Actual reported data between 2000 and 2008 show HCFC consumption in developing countries to have grown at a steady annual pace of 15% from 8000 ODP tonnes to 31 000 ODP tonnes, as shown in Figure 2.3.

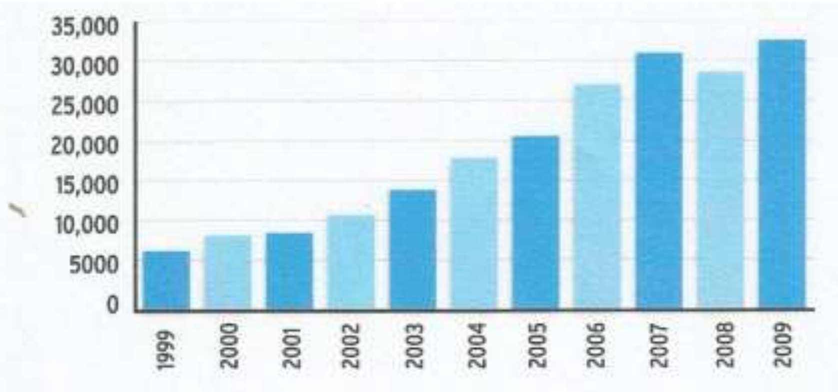


Figure 2.3: Consumption of HCFC in developing countries
Source: UNEP (2011b)

A minor drop in consumption occurred in 2008, which was assumed to be a result of the global economic downturn (UNEP, 2011b). Calm (2008) reported that HCFC-22 is the most used refrigerant in Taiwan because it is sourced mainly from the domestic producer. According to Tsai and Chou (2008), consumption of HCFC-22 will gradually increase because it is cheaper than other HCFCs. Calm (2008) confirmed that the use of HCFC-22 is mainly due to the fact that it is domestically manufactured.

According to the UNEP (2011b), consumption of HCFC in Mexico increased from 14 114.9 MT in 2005 to 19 011.2 MT in 2007 and then decreased to 14 596.7 MT in 2010. The compliance baseline is approximately 1148.8 ODP tonnes. The 2007 expansion in HCFC-22 usage was caused by a 13% surge in production at the national level and a 31% shrinkage in exports. AS a result, HCFC-22 inventory on hand was used to meet the bulk of the demand in 2008. The UNEP (2011b) reported that in Mexico HCFC-22 consumed represented over 98% of total consumption in the country and 52% of the total HCFC imports in 2010.

The UNEP (2015d) reported a 21% global consumption of HCFC-22 in Asia, Africa and Latin America. Article 5 countries are responsible for a relatively small amount of HCFC-22 emissions. North American, Japanese and European latitudes currently see the bulk of emissions of HCFC-22. The UNEP (2010b) reported that HCFC-22 consumption in Article 5 countries will be frozen in 2013 and then be decreased in steps, with a complete phase-out due by 2030.

The most interesting factor to note from the above empirical evidence is that emission follows consumption. Consumption is likely to be as a result of the fact that a country has a huge industry manufacturing cooling systems, consequently exporting more. Thailand, Philippines, Indonesia, Malaysia, Vietnam and Singapore were the top 6 HCFC-22 consumers (out of 25 Article 5 countries) because of the presence of many producers of air conditioning equipment (UNEP, 2010b). The other fact could be that owing to a country's climate conditions, HCFC usage can either go up or down. It follows that a country with high temperatures will manufacture or import more products that use HCFC-22.

In reporting on their survey, Midgley and Fisher (1993) suggest that during the period 1980–1991, the portion of total HCFC-22 released in the Southern Hemisphere was very small and approximately 90% of total production was sold in the industrial north (30^{o} N-90° N). Wu *et al.* (2013) observed significantly higher levels of HCFC-22 in the urban atmosphere, which might probably reflect the greater population density in urban areas.

The first atmospheric measurements of HCFC-22 taken at the Cape Point Observatory (CPT) in SA during 2017 found that Cape Town was the dominant source in South Western South Africa (SWSA). SA's HCFC-22 emissions for 2017 were estimated to be 3.0 Gg year^{-1} and this contributed to less than 2.5% of global emission (Kuyper *et al.*, 2019). Happily, it would seem numerous African countries are compliant with the MP, with a sizeable number in fact being ahead of the scheduled timelines in the phase out of ODSs. The reason seems to be that the majority of African countries, save for the few leading developing ones, are minor participants in the manufacturing, exporting and emission expelling activities in the world. More atmospheric monitoring and research work, however, still needs to be done in order to verify and monitor actual compliance levels.

2.9 **HCFC-22 phase-out strategies in developing countries**

The phase-out of HCFC-22 is a significant strategy that the MP signatories have agreed to. According to Fortems-Cheinrey *et al.* (2013) and Yoshida (2018c), the MP signatories have an obligation to report their annual consumption, that is, production plus imports minus exports of HCFC-22 and other ODS to the UNEP. At the 2007 19th conference, it was agreed to speed up the phase- out of HCFCs only dealing with the dispersive application, with the exception of the fluoropolymer manufacture feedstock (UNEP, 2007). In Article 5 countries, the phase out of HCFC-22 was planned to have been largely completed by 2030, aiming to reduce the consumption by 97.5% with a base level in 2009-2010 (Fortems-Cheiney *et al.,* 2013; Wang *et al.*, 2016). The phase-out in developed countries was also planned to have been mostly completed by 2020, with consumption being reduced by 99.5%. Exports for virgin HCFC-22 in Non-Article nations after 2020 will be for servicing the existing refrigeration and air-conditioning equipment in Article 5 parties. It has been reported that developed countries in Europe are in compliance with the phase-out schedule of HCFC-22, with phase-out in the United States almost reaching completion (UNDP and GEF, 2017; Ortlieb, 2019).

In developing countries, as per the amendments to the MP, the final year of the HCFC-22 consumption phase-out is 2040. The period for consumption phase-out shall be longer, and the consumption and production baseline year shall be 2015; the consumption and production baseline levels are the 2009 and 2010 mean consumption and production respectively (UNEP, 2012a; Koszegvary, 2013). It is expected that emissions of HCFC-22 will continue in the long term despite consumption controls owing to the significant quantities of HCFC-22 remaining in existing equipment. However, as feedstock production does not have the same HCFC-22 release effects as its dispersive counterparts, it shall be allowed to continue indefinitely to be produced in any part of the world (UNEP, 2003; 2012a). The target phase-out timelines for HCFC-22 is as follows:

Table 2.1: Target phase-out timelines for HCFC-22 in developing countries

Schedule	Year
Baseline	Average of 2009 and 2010
Freeze	2013
10% reduction (90% baseline)	2015
35% reduction (65% baseline)	2020
67.5% reduction (32.5% baseline)	2025
Complete phase out	2030
2.5% of baseline averaged over 10 years for servicing of refrigeration and air conditioning equipment.	2030–2040

Source: Koszegvary (2013)

To assist developing countries fulfil their MP implementation obligations, the Multilateral Fund (MLF) was set up to provide them with funding (Andersen, 2015; Al-Awad *et al.*, 2018). Some of the issues agreed to by the parties in relation to the HCFC-22 phase-out schedule, according to Koszegvary (2013), were that the MLF would provide stable and adequate funding to meet the incremental requirements of the accelerated HCFC-22 manufacture and use phase-out schedule for developing countries. An extension of that was that the MLF Executive Committee was mandated to adjust the criteria for eligibility based on facilities relating to the period after 1995 and the second conversions. According to UNEP (2020) report, the MLF executive Committee approved US $176 000 and US $904 000 for Angola to meet her 10% (2011-2015) and 67% (2017-2025) reduction in HCFC-22 consumption. During the 67th meeting with the MLF Executive Committee, Namibia submitted the intention to phase-out completely the consumption of HCFC-22 by 1st of January 2020. The MLF Executive Committee approved a sum of US $900 000 for the period 2011- 2025 with the understanding that there would be no more funding eligible for HCFC phase-out in the country after 2025 (*ibid.*). The funding was also conditional on countries preparing a plan for the management of the phase-out of HCFC, which detailed HCFC consumption and uses by substance and product. The HPMP also presents patterns of growth and identifies priority sectors to receive MLF funding in order for developing countries to achieve their reduction targets for Stage 1. Generally the MLF was not was not sufficient for developing countries to convert HCFC to new technology. For example, UNIDO (2015) reported that Botswana has not carried out investment projects of converting HCFC-22 to new technologies through the MLF.

2.10 **Country-level HCFC-22 phase-out compliance strategies**

The MP has scored significant success in the reduction, manufacturing and consumption of HCFC-22 and is expected to lead to the complete phase out thereof by 2030 (UNEP, 2012a; Wang *et al.,* 2016). For the HCFC-22 phase-out efforts to succeed, it is crucial that countries have appropriate policy frameworks suited to their specific circumstances. In fact, most countries have already launched appropriate initiatives to address the management of the phase out of the refrigerant. Generally, the literature discussed in this section focuses on the phase-out plans of MP signatories which include regulatory, non-regulatory and funding/resourcing interventions

2.10.1 Regulatory interventions

Most countries have some regulations which facilitate the execution of the provisions of the MP and, by extension, the HCFC-22 phase-out schedule. Gloel *et al*. (2017) observed that ODS regulations have been instituted by most developing countries to guide MP implementation and its associated ODS phase-out provisions and schedules. All these regulations are centred on controlling the manufacture and import of restricted substances, including HCFC-22. Some of the issues dealt with in these laws are about how to handle gases, the necessity of gas recovery at the stages of servicing and decommissioning, activities related to the collection, training and certifying technicians, enforcing regulations, bans on some products, control of leakages and reporting. Often, national laws are amended in line with MP amendments or when new phases start. With the exception of MP regulations and the attendant schedule for phase out, bans on usage or on some products might be imposed on given substances or products operating on certain substances. One way of ensuring there is no influx of ODS containing equipment is to impose a ban on the importation of used equipment (Gloel *et al*., 2017).

For example, according to the UNEP (2012b), various laws and regulations have been instituted in South Africa to control the importation, exportation, consumption and usage of HCFCs, with the ultimate goal of complete ODS phase-out. Collectively, these are called the Regulations Regarding the Phasing out and Management of ODS Regulation 351 of 8 May 2014 (UNEP, 2016c). Such laws and regulations include the Air Quality Act 39 of 2004 which imposed importation and exportation licences; the Department of Environmental Affairs (DEA) Regulation 33925 of 2011, which imposed quotas to limit HCFC-22 importation in line with the MP confines commencing 1 January 2013; and the National Standard 10147 of 1994 which includes a code of practice for decreasing ozone depleting refrigerant emissions.

The UNEP (2013b) also details the steps taken by Ghana and Mauritius to control HCFC-22. The former, through a framework of laws for the management of HPMP, banned the importation of all used refrigeration equipment from 1 January 2013 (UNDP, 2018). The latter, as part of a similar plan, froze imports of refrigerants and refrigerant containing equipment from January 2013. Similarly, in January 2013 the importation of HCFC-containing appliances and equipment was banned in favour of alternatives, then available in that country, like carbon dioxide, ammonia and hydrocarbons.

For its part, the government of Argentina imposed legislation which strictly prohibits the purchase or import of HCFC-22 for production of domestic air conditioning appliances as of 1 January 2013. Since 2013, manufacturing and assembly of domestic air conditioning appliances containing HCFC-22 is prohibited. Moreover, as of 30 September 2013, the sale of domestic air conditioning appliances containing HCFC-22 was prohibited. However, manufacturers in the duty-free zone of Argentina can manufacture for export but are controlled by customs and are required to comply with MLF regulations (UNEP, 2016d). This action along with good quality control of their final product was envisaged to enable the sector to survive in the long run (UNEP, 2016d).

The major legislative step taken by the Thailand government to reduce demand for HCFC-22, accelerate the adoption of more energy efficient technologies and meet MP targets was to ban the manufacture of domestic HCFC-22 based air conditioners in 2017 (*ibid.*). Alongside this, the country has developed regulations to ban the import of all HCFC-22 based RAC equipment with an anticipated implementation date before the end of 2016. The Islamic Republic of Iran passed legislation which since 2010 has prohibited the creation of new HCFC-22 consuming industrial units as well as the expansion of capacity of such enterprises (UNEP, 2016d).

It was observed, however, that although most Pacific Island countries have instituted ODS regulations, there are some that still require help with systems, regulations and legislation for licensing and other aspects (UNEP, 2013b). Guidance is needed in all the countries on how to effectively enforce the licensing system, legislation and regulations.

The UNDP (2011) noted that ever since Angola became a member of the MP, the country has depended on existing ODS legislation for implementing HCFC phase-out programmes and meeting its obligation to the MP. This has been achieved through institutional measures that take advantage of the association of functions of organisation under that legislation. Furthermore, the Government of Angola has introduced moves to consolidate the regulations to provide for a licensing and quota system for ODS importation in the country. In Botswana, the Meteorological Act of 2014 and the ODS regulation of 2014 were established to regulate the phase out of HCFC-22. The country has also depended on this legislation and HPMP to implement the licensing and quota system (Government of Botswana (GoB), 2014a; 2014b).

2.10.1.1 *Control of ODS imports in developing countries*

To control imports and exports of ODS, most SADC countries have implemented licence and quota systems that cover HCFCs. Their enforcement and implementation vary significantly from country to country (Koegelenberg and DEA, 2019). Although most countries reported having ODS import control measures, verification of HCFC-22 consumption shows discrepancies between import data kept by customs departments, licensing departments and NOUs. This has been credited to the following:

- Inappropriate or incorrect declaration of HCFC codes during the customs clearance process, especially where an ODS consignment is cleared in a batch with other supplies.

- Importers are granted customs clearance without a valid import/export licence issued by the responsible authority.

- Illegal trade of ODSs.

- Absence of an operational mechanism to track imported ODSs after the import licence is issued to the importer/exporter in cases where the trade is not in accordance with the issued licence.

- Lack of periodic reconciliation of ODS consumption data with importers, customs department, NOU and licensing authorities.

In SA, the Customs and Excise service identifies ODSs with special tariff codes. The DEA and the NOU use the same tariff codes for recommendations to the International Trade Administration Commission (ITAC) and for import and export permit issuance. It is expected that the control and monitoring of the imports/exports into the country of ODSs should result in their consumption correspondingly decreasing (DEA, 2018a). In Rwanda, the UNEP (2018c) reported that the government had implemented a licensing system for the control of ODS imports since 2007 and in 2013 the ODS regulations were revised to include the control of HCFCs. The country has a well-established enforceable licensing and quota system to control HCFCs consumption in the RAC sector.

To create a legal framework for the control of ODSs, the government of Botswana reviewed the National Meteorological Services Act of 2014 to include ODSs Regulations in 2014, which incorporated stipulations limiting the importation/exportation, sale, purchase and usage of ODS including HCFCs. Specifically, the amendments imposed licensing requirements and quotas on imports of HCFCs and equipment using the same, thus ensuring that Botswana complies with its MP obligations (UNEP, 2015a; 2018a).

The UNEP (2011c) observes that the UNDP identified Angola as one of the countries in which a licensing and quota system was instituted for all ODS, HCFCs included, with effect from 23 June 2011. Similar information was reported to have been submitted by Angola, in line with

Article 4B of the MP, to the Ozone Secretariat. In 2016, the UNEP made field assessments of the HPMPs of eight countries and found that seven of them, namely, Argentina, China, Indonesia, Jordan, Iran, Lebanon, and Thailand with the exception of Serbia, had enforceable systems for licensing and quotas in place during the field visits. During implementation of Serbia's HPMP, priority was given to new regulation on ODS management, as well as on conditions for licence issuance to import and export such substances (UNEP, 2016c). The UNEP (2018c) reported that Belize implements the MP resolutions under the Ministry of Agriculture, Forestry, Fisheries, Environment and Sustainable Development, which legally grants the ODS import licences and set the HCFC quotas, and grants import authorisation of refrigerant-based equipment such as refrigerators and air-conditioning units.

The quotas and licensing system implemented in Botswana is in line with decision 63/17 of the MP. In 1994, Botswana was classified as an Article 5 country (UNEP, 2011a; 2012a) with a low per capita consumption of ODS estimated at 0.02 kg (Ntakhwana, 2018). The quota for 2015 was issued at 180 MT (9.90 ODP tonnes) (UNIDO, 2015).

2.10.1.2 *Annual data on consumption/importation*

The researcher notes that tracking annual consumption of HCFC-22 against baseline figures is not easy in some instances due to gaps in data collection and/or access. For example, according to the UNEP (2011c) Angola, without HCFC-22 manufacturing capacity, imports all the HCFC-22 it uses. The country, owing to a lack of data collection capability, could not report its HCFC-22 consumption data for the years 2006 and 2007 in line with Article 7 of the MP. Furthermore, according to the UNEP (2011c), the war in that country meant that monitoring and licensing systems for ODS were non-existent in 2005–2007. The UNDP (2011) forecast the increase in growth of ODS consumption to settle at about twice the GDP growth, which is usual for the comfort goods industries. The Government of Angola approved the establishment of a HCFC phase-out consumption aggregate reduction baseline calculated on the average of the actual reported consumption of 19.25 ODP tonnes in 2009 and of 12.65 tonnes in 2010, amounting to 15.95 ODP tonnes.

According to Yin (2012), Singapore introduced a quota system for HCFC-22 importation. Each company is given this quota confidentially, meaning it is not publicised. Quotas are transferable within companies subject to application and approval. These applications for quota transfer are opened twice a year in April and October (*ibid.*).

South Africa appears to have a more comprehensive consumption monitoring and reporting system. The DEA (2018a) notes that there was a tremendous drop in the consumption of HCFC-22 to 3821.1 MT. From 2014 to 2016 there has been a consistent drop in HCFC-22 consumption with 2014 consumption at 3 558.5 MT, 2015 at 3 155.6 MT and 2016 at 2581.4 MT. This may be attributed to the existing management and controls through the ODS management and phase-out regulations and provisions set out by the MP for parties, with the final 2040 target being a complete cessation of usage of HCFC-22 **(***ibid.*). In Botswana, the UNEP (2015a) observes that HCFC-22 consumption levels have remained stable since 2009 (Table 2.3), as alternative refrigerant and air-conditioning equipment is increasingly available and awareness has increased, thanks to the awareness-raising activities of the NOO. The drop in HCFC-22 imports in 2013 is indicative of this increased awareness of HCFC-22 phase-out among the service industry, which is leading to changes in the equipment being used in the country. In particular, there is an understanding of the transitional nature of HCFC-22; hence industry and end-users are made to see the merits of using non-HCFC-22 equipment.

2.10.1.3 *National zone units*

The World Bank (2014) reports that a number of countries have established ozone units in compliance with the recommendations of the MP and its subsequent amendments. Thailand, for example, established her NOU in 1992 within the Department of Industrial Works (DIW). Its main responsibility is to ensure Thailand's compliance with its obligations under the MP, especially the monitoring of imports and exports of ODSs, implementing import quota systems for ODSs and liaising with other government agencies including the Customs Department to ensure the effective control of the borders to pre-empt any illegal shipments of ODS in and out of the country. The same success has not been witnessed everywhere however. In Serbia, the NOO shut down and was not replaced for two years, leading to delays in project implementation and difficulties in communication between UNIDO and recipient enterprises (UNEP, 2016a).

Similar units have been developed in English-speaking countries with the same objective of ensuring sustained conformity to the provisions of the MP and its amendments (UNEP 2013b). This is done by regularly updating and guiding countries on the various MP compliance requirements, as well as on how to implement the associated phase-out activities required in order to comply with the MP and its amendments (*ibid.*).

Ghana established its NOO in 1991, as part of the EPA (UNDP, 2018). This was a partial response to its commitments in accordance with the MP, which it ratified on 24 July 1989 (UNDP, 2018). The crucial importance of institutional strengthening and supporting the NOO is acknowledged. The traditionally consumed HCFC in Ghana has been HCFC-22. Its uses include as a refrigerant in the residential and commercial air-conditioner servicing sector, in chillers and larger industrial and commercial refrigeration equipment. Yin (2012) reported that Singapore launched a new HCFC phase-out website in 2012, which enabled access to information on HCFC phase out in Singapore.

In Bahrain, the UNEP (2018c) reported that all MP associated issues are integrated into the national environmental plan through the NOU, which is the integral part of the Council for the environment. The NOU has established an e-licensing system which has managed to effectively control the import/export of ODS, as well as provide timely and accurate reports containing ODS information. The Government of Malawi has also established an NOU which effectively controls quotas for importers and the licensing system (*ibid.*).

2.10.1.4 *Disposal of ODS equipment*

Another criterion for tracking ODS phase out is the disposal of equipment making use of ODS. Although all nations worldwide have agreed to phase-out the production and consumption of HCFCs in line with the MP, no agreement has been reached concerning disposal or destruction of equipment. Froelich (2015) states that the collection, destruction and recycling of waste equipment containing ODS in developing countries has been a challenge, as most developing countries lack appropriate infrastructure and a regulatory framework.

By way of example, the UNEP (2016a) reports that their field assessments in 2016 indicated that with the exception of Thailand, Argentina, China, Jordan, Iran and Lebanon, ODS manufacturing equipment that could not be reused in new manufacturing lines was destroyed. Vacuum pumps, leak detectors and charging machines (retrofitted) were retained. In Thailand, all equipment has yet to be destroyed and verified by the NOU. Many of the enterprises have kept some HCFC-22 for the servicing of their products under warranty (*ibid.*).

The UNDP (2011) reported that Angola has 18 recovery units and four recycling centres to assist the country recover and recycle HCFCs. It was further noted that the recovery units and recycling machines were in good condition, with the exception of those in the Luanda Training Centre that were damaged as a result of heavy rains and subsequent flooding which destroyed the centre in January 2007. In Bahrain, the UNEP (2018c) reported that Bahrain had established an ODS reclamation centre in December 2017. Froelich (2015) also reported an ODS reclaim facility that was installed in Bogota, Colombia with 14 technicians trained in the installation and operation of the facility. The UNEP (2016c) also reported that in 2014, SA declared the mandatory recovery and recycling of ODS. Accordingly, any person or entity conducting recycling or recovery of ODS must have a waste management licence and those with ODS destruction facilities must possess an atmospheric emission licence (South African Government Gazette, 2014). According to Letsholo (2019), the government of Botswana has not yet constructed warehouses and destruction facilities for ODS but plans are underway.

2.10.1.5 *HCFC-22 phase-out obligation*

The MP and its subsequent amendments stipulated specific timelines and targets that the signatories had to meet in terms of the phase out of ODS. For instance, Australia, one of the early signatories to the MP, leads in ODS phase-out, having thus far met or surpassed all her MP phase-out commitments. Projections were that by 2016 the country would have ceased consumption (manufacture plus imports, minus exports) of HCFC-22. This would have beaten her MP schedule target by four years. The net result of this is that her HCFC-22 consumption up to 2020 would have been 61% less. These results were achieved thanks to cooperation and partnership involving industry, the community and all governmental levels (Australia Government, 2015). HCFC-22 phase-out achievement for some selected developed countries are summarised in Table 2.2.

Table 2.2: HCFC-22 phase-out achievements for some selected Article 5 countries

Country	Progress towards HCFC-22 phase-out
Sierra Leone	• Has implemented Stage I of HPMP with baseline HCFC consumption of 1.70 ODP tonnes. • Achieved its HCFC-22 10% reduction in 2015. • The country reported consumption of 0.61 ODP tonnes in 2016.
Barbados	• Ensured conformity to MP reporting and regulatory requirements as follows: • Licensing and quota system was implemented. • Data flow on ODS to the Fund and Ozone Secretariats. • Educating the public and raising awareness through various activities. • Attending MP meetings regionally and internationally. • HCFC phase-out and HFC phase-down information dissemination to national stakeholders.
Lesotho	• ODS regulations implemented by enforcing the licensing and quota system. • RAC technicians and customs officers trained through regional workshops. • HPMP Stage I, second tranches coordinated.
Saudi Arabia	• Met its MP obligations by collaborating with the Saudi Customs Authority (SCA). • Saudi Standard Organisation (SASO) and Civil Defence and putting their enabling legislation to good use to achieve a common goal. These collaborative efforts are coordinated through the NOU.
Namibia	• Made significant development in phasing out HCFC-22 and adopted ozone and climate responsive technologies. • Has been in compliance with the MP control targets and HCFC-22 consumption for 2015–2016 was lower than the maximum permissible consumption limits agreed by the government and the MP. • Already reduced HCFC-22 consumption significantly by 80% from the baseline, aiming to phase out HCFC-22 by 2020, 10 years earlier than 2030. • Endorsed HCFC regulations which ban the importation of equipment that uses HCFC. • Established HCFC imports/export quota system and keeps records and monitors whether HCFC-22 reduction progress is achieved.
Zimbabwe	• The HCFC-22 import licensing and quota systems are functional. • Has already reduced HCFC-22 consumption in 2015 by 17% below the maximum permissible consumption.
Malawi	• Enacted the ODS regulations and implemented the quota and licensing systems. • Implemented HCFC-22 awareness activities which targeted main stakeholders (importers, border control police officers, refrigeration technicians and customs officers). • Started activities for HFC phase down.
Mozambique	• Enacted the ODS regulation and implemented the quota and licensing systems. • Carried out HCFC-22 awareness activities. • Trained refrigeration officers, customs officers and law enforcement officers. • Participated in regional network and MP meetings. • Prepared a proposal allowing HFC phase down.

Source: (UNEP, 2015e; 2017c; 2018c; Nakale, 2018)

2.10.2 Non-regulatory interventions

The non-regulatory interventions support regulatory measures and are carried out independently in order to facilitate HCFC-22 phase-out. These include:

2.10.2.1 *Exchange of information on HCFC-22 phase-out*

Articles 4 and 12 of the MP require countries to embark on national communications to disseminate information on the implementation of the MP to educators and health personnel, respective councils, governmental and non-governmental organisations, refrigeration practitioners and other stakeholders. Importantly, this information includes that about the specific ODSs, their effects, as well as the various implications of ODS phase-out (UNEP, 2016a). In Thailand, Daikin Manufacturing conducted massive public advertising campaigns on the efficiency and safety of HFC-32 products (substitute of HCFC-22) (Nicholson and Booten, 2019). This campaign has been so successful that consumers are demanding HFC-32 air-conditioning products. Government support was seen in Argentina, where, at the time of the conversion, appliances using HCFC-22 were cheaper than those using R-410A (UNEP, 2016a; Shah *et al.,* 2017). Ozone Day celebrations were held in Angola, Malawi and Lesotho on 16 September 2018 and information dissemination meetings and workshops were organised across these countries (UNEP, 2018c).

For its part, South Africa's environmental authorities held a series of stakeholder meetings on the adoption and enforcement of the HCFC-22 control measures promulgated (Cole *et al.,* 2017). The measures to make HCFC and refrigerant recovery and recycling mandatory, originally planned for 1 September 2014, are currently under negotiation with sector counterparts (UNEP, 2016e; Shah *et al*., 2017).

The UNEP (2018c) reported that Bahrain has updated its HPMP to 2023, implementing public awareness, including the celebration of the international Ozone Day, and participating in the MP and regional network meetings. Botswana's plans were to organise seminars and workshops and make use of the local press and media, art and competitions. In July 1995 and March 1997, Botswana hosted two such awareness-raising and environmental policy-related seminars with a focus on global warming and climate change (United Nations (UN), 1997). Additionally, the country has prepared and delivered several briefings to inform authorities about the UNFCCC and its expected social and economic impacts (UNEP, 2011a; 2018c). The government of SA in collaboration with the United Nations Environment Ozone Action organised a fruitful workshop to strengthen the coordination and controls of ODS in the SADC region. The workshop was attended by SADC nation representatives (NOU, customs officers and environmental inspectors) from 24–26 October 2018 in Johannesburg (Koegelenberg and DEA, 2019).

2.10.2.2 *Research on HCFC-22 phase-out*

An important part of the MP resolution is research, especially into environmentally friendly alternatives to HCFC-22. Moves have already been made to replace the ozone depleting HCFC-22 with HFCs like R410A and R407C (in keeping with the KP) (Liu *et al.,* 2019). Thus, extensive research continues globally to find an environmentally sustainable, zero-ODP and low-GWP alternative to HCFC-22 (Kalla *et al.,* 2018).

The UNEP (2013c) and DEA (2018a) note that the Government of SA has conducted preliminary meetings, publications and workshops with stakeholders with the objectives of engaging industry, rolling out the HCFC-22 phase-out strategy, putting technology experts at the disposal of stakeholders, and presenting South African studies and pilot projects. In pursuit of the HCFC-22 phase-out, Yin (2012) noted that Singapore facilitated information exchange with other regional countries and carried out a technical feasibility study of HCFC-22 alternatives. SADC countries united to hold a workshop on controlling ODS. The use of iPIC, information sharing, research on alternative refrigerants and the need to formulate whistle-blowing policies were discussed (Koegelenberg and DEA, 2019).

2.10.2.3 *Customs officers and technician training*

For Gloel *et al*. (2017), the training and certification of qualified refrigeration and air conditioning (RAC) servicing personnel and the usage and handling of HCFC-22 refrigerant is a measure with huge potential to ensure adequate qualification of service sector refrigeration technicians, as well as the application of the best containment practices when installing, maintaining and repairing refrigeration equipment. Integrating technician certification in legislation is an effective way to guarantee the proper handling of ODS and emission reductions. For instance, the Slovak Republic's electronic system, introduced in 2010, links training and certification with data processing and reporting (Gloel *et al.,* 2017). Included in their system is a section dealing exclusively with the electronic recording of equipment data and information on leak tightness (leak log) and another for electronic reporting and certification.

The Republic of Bulgaria reports that in view of the problem of illegal imports of ODS, custom training was prioritised and implemented through the Bulgarian ODS phase-out project (UNDP, 2018). The custom training component also included equipment for the detection of refrigerants, which was also done by Ghana (UNDP, 2018). Customs officials at that country's southern port and borders were trained in imported refrigerant identification. Through the

Ghana Refrigerant Recovery Recycling Project (RRRP) the contracting, training and equipping of eleven refrigeration centres was facilitated in order to capacitate them to convert air conditioners to environmentally friendly refrigerants. This initiative saw an estimated 11 tonnes of HCFC-22 being recovered from 4531 HC-290 converted air conditioners by December 2015. Ghana has also set up the Centre of Excellence in Refrigeration and Air Conditioning at the Accra Technical Training Centre to train government agencies, electricians and refrigeration operators in the usage and handling of hydrocarbon refrigerants, with two more in the pipeline. These centres have greatly improved the capabilities of refrigeration practitioners and technicians (UNDP, 2018).

In Zambia, according to the UNEP (2016e), an initial ten sets of servicing tools were procured and distributed to the Refrigeration and Air Conditioning Association of Zambia and the servicing centres. Technicians were trained on the proper use and maintenance of the tools, and awareness campaigns were conducted to promote the centres so that technicians could access the equipment. Another phase was implemented comprising the following: training of customs and law enforcement officers on enforcement of ODS policy and regulations; safe handling of refrigerant cylinders during inspections; and the use of refrigerant identifiers.

In Zimbabwe, according to the UNEP (2011d), under that country’s terminal phase-out management plan (TPMP), an estimated 1000 technicians received training. However, due to the economic crisis and the resulting brain drain over the years, the number of technicians remaining in the country is difficult to reckon. Under Botswana’s HPMP, 150 customs officials went through various training workshops; ozone now features as a major activity in BURS programmes, and ozone protection is a major discussion topic in regular senior staff debriefings and meetings (UNIDO, 2015). The corresponding number of refrigeration technicians for the same period was 300. In fact, more than 20 training sessions were carried out between 2000 and 2013, driven by the Gaborone Technical College (GTC) through its partnership with the NOO of Botswana (UNIDO, 2015). The training of technicians stressed good practices and retrofitting techniques as well as the recovery and recycling of CFCs (*ibid.*).

2.10.3 Monetary/resourcing interventions to support developing countries

To assist Article 5 countries to fulfil their obligations as per the MP, the MLF for the Implementation of the MP was set up in 1991 (World Bank, 2014). The details of the funding were to cover funding for the phase-out of ODSs and technical assistance for Article 5 countries whose annual per capita production and consumption of ODSs is below 0.3 kg (UNEP, 2018d).

The UNEP (2018d) explains that the MLF is characterised by the following: it foots the incremental expenses that developing countries incur in the process of complying with the obligations of MP; an Executive Committee comprising 14 members split equally between developed and developing countries exercises oversight over the operation of the Fund. These members have equal rights and say over the affairs of the Fund. Four international agencies (UNIDO, UNDP, UNEP, World Bank) and several bilateral government agencies implement relevant activities. The MLF has an independent secretariat co-located with the UNEP. Since 1991, the MLF has funded activities in the areas of technical assistance, industrial conversion, training and capacity building. Expectations were that these activities would reduce consumption and production of ODS in Non-Article 5 countries by almost 460 000 ODP tonnes. One country that has benefitted from the MLF is South Sudan. In this country, which was the 197th signatory to the VC and MP, two ozone protection multilateral environmental treaties started their debut Montreal Protocol project financed by the MLF in 2013 (UNEP, 2013b).

Botswana, like other developing countries, qualifies for funding and technical support from the MLF in order to reduce and eventually completely phase-out ODS usage (Ntakhwana, 2018). As an MP signatory, Botswana is obliged to furnish the Implementation Committee with its annual ODS consumption information. The country also has to come out with a phase-out plan for ODS, promote the use of alternative refrigerants, apply the funding to carry out vulnerability and feasibility studies, and train national experts to refine its national ODS stocks (Ntakhwana, 2018). The emphasis of the funded projects will be on developing strategies for the mitigation and adaptation of given various climate change possibilities.

The Fund, according to the UNEP (2018d), has seen over 8600 projects and activities executed in Article 5 countries, facilitating technology transfer from old to new technologies. Over 145 NOUs were set up as part of capacity building and institutional strengthening. To enable the sharing of information on regulations and legislation, regional networks of Ozone Officers from over 100 signatory countries were established. There have been nine reimbursements to the MLF up to now, and the sum total of contributions has surpassed US$ 3.9 billion (Andersen, 2015; UNEP, 2015b; 2018d).

However, the UNEP (2016d) notes that there have been challenges to implementation of some ozone-related projects. In fact, most enterprises in all countries experienced some delays in the procurement and delivery of equipment made available by the Fund for various reasons. In the Islamic Republic of Iran, for example, the project was delayed for more than one year because of the economic sanctions (UNEP, 2016d). The enterprise, Mehr Asl, missed some deadlines and had to sign amendments to the agreement concerning the new schedule. The delays relate to the late arrival of machinery, more specifically of compressors, which were also retained for a long time by customs (UNEP, 2016d). In addition, the UNDP changed its payment modality from US dollars to euros, which forced the enterprise to change its money transferring mechanism, and caused delays in payments to the subcontractors. Another challenge was that other than Indonesia and Thailand, international enterprises did not appear to have any influence on the selection of new technology refrigerants. In Indonesia, Panasonic adopted the new HFC-32 technology and began production, and may be considered a trendsetter that may influence the market *(ibid.).*

The MLF has also significantly contributed to technology transfer. According to the UNEP (2016d), the key criterion to be considered in the process is the selection of alternative refrigerants and their operating systems based on a thorough analysis that includes energy efficiency, environmental impacts, safety, economic considerations as well as social consequences. Additionally, capacity building activities related to updating information on replacement technologies which are feasible from economic and technical perspectives and have application potential for local RAC manufacturers vary from country to country. Various professional bodies and associations have been involved in this activity in the early stages of technology selection, but it is not clear whether there is continued support in this regard (Shah *et al.*, 2017). The NOUs also played an important role. During its HPMP preparation phase, the Islamic Republic of Iran together with the NOU and the implementing agencies conducted a review of the technology options available (UNEP, 2016e). Accordingly, R410A was selected to replace HCFC-22 as an internationally accepted refrigerant (UNEP, 2016e; Nicholson and Booten, 2019). Other than Indonesia and Thailand though, international enterprises do not appear to have any influence on the selection of new technology refrigerants (*ibid.)*.

Although other countries have already recorded successes, the UNEP (2016e) observes that enterprises in Argentina, China, Jordan, Iran, Lebanon and Thailand have completed their conversion of air conditioning units from HCFC-22 to HFC-32a. However, other than Panasonic Indonesia, none of the enterprises have started production of HFC-32a based units, since there is no demand for the product. In Thailand, Daikin Manufacturing has not only contributed to training programmes but has also conducted massive public advertising campaigns on the efficiency and safety of HFC-32 products. This campaign has been successful and consumers are demanding HFC-32 air conditioning products (UNEP, 2016e).

Some authors, for example Gloel *et al*. (2017), have proposed incentives for end users in order to speed up energy efficient and environmentally friendly technology adoption and transfer, ultimately easing demand for energy. Possible incentives could be discounts or tax cuts on the purchase of new non-ODS equipment, or a trade in arrangement on old equipment. Examples of the latter are the refrigerator take-back programmes of Mexico and Brazil, also called “new for old” programmes (UNEP, 2016e). Some of the practices for achieving these goals include actual donation of refrigerators to low-income earners to subsidising the purchase of new ones by up to 50%. Colombia’s planned approach has been to reduce value added tax (VAT) on domestic refrigerator purchases (UNEP, 2016e).

The UNEP (2015b) records one of the singular achievements of the MP as the high levels of compliance exhibited by the parties. The compliance rate of all MP signatories is above 98% (*ibid*.). Furthermore, a significant number of both developed and developing nations have exceeded their phase-out schedule commitments. This has been thanks to both the financial assistance offered to signatories as well as the positive non-compliance procedure which helps non-compliant parties become compliant.

The effort to maintain high rates of compliance are hindered by illegal trade, fuelled by the alternative markets emanating from the diminishing ODS supplies. Gloel *et al.* (2017) identified a number of reasons for non-compliance, including wilful non-compliance (for example for economic gain, and time and effort savings), knowledge gaps in relation to regulations, incompetence, lack of frameworks for compliance, and public and private financial limitations. To deal with these hindrances, training has been provided to raise awareness and disseminate information to stakeholders and increase competence. Rebates and subsidies are seen as having the potential to encourage the use of alternatives to ODS and reduce economic constraints. Finally, to avoid unfairness caused by lax enforcement, which favours free riders, the enforcement strategy must be integrated into the planning stage of any new policy measure.

2.11 The socio-economic and environmental impacts of compliance to the Montreal Protocol

2.11.1 Socio-economic challenges from HCFC-22 phase-out

In as much as the phase-out of HCFC-22 will greatly contribute to reducing the destruction of the ozone layer, the resulting effects of such initiatives cannot be ignored. Among some of the challenges are illegally traded ODS refrigerants, a higher incidence of mixed and fake refrigerants, equipment failures, court cases as well as the handling of refrigerants after seizure, and that of ODS-based equipment (UNEP, 2013b; Gonzalez *et al.*, 2015; Yoshida, 2018a; Protocol, 2019). The HCFC-22 phase-out has been put into effect through the MP. According to the UNEP (2011b), many countries have gone a long way to supporting this process by reviewing their legal structures to accommodate the strategy implementation results of illegal trading. This logic has not spared the gas energy sector worldwide. The problem of illegal trade in ODS first began in the mid-1990s, as the ban on the manufacture of CFCs and halons became operational in industrialised countries (Newman, 2000; EIA, 2016; Protocol, 2019). This resulted in the USA, China and Russia being heavily involved in the illegal trade and supply of ODS.

As the supply of HCFC-22 decreased it resulted in price rises and the temptation to engage in the black market and illegal trade (UNEP, 2010c). The introduction of the licensing systems to prevent the black market and illegal trade in HCFC-22 have resulted in developed countries dumping ODSs and ODS operated equipment in developing countries (Gorman, 2005; Rucevska *et al.,* 2015). The UNEP (2010c) reported that there was abuse of non-producing countries and free trade zones to move ODSs, thereby avoiding the MP licensing system. The UNEP (2010c) noted that mislabelling and false declarations make it a challenge for customs to identify ODS goods. A lot still needs to be done to reduce smuggling in developing countries whose ODS phase-out is yet to be completed, hence they account for the bulk of production and consumption of ODS (*ibid.*).

According to Newman (2000), Liu *et al*. (2016) and Protocol (2019), the major case of ODS smuggling taking place in Europe has been exposed. The illegal materials from China were sold on to customers in France, Belgium, the UK, Greece, Italy, Hungary and the USA. The illegal trade in HCFC-22 presents a risk of severe damage to both the ozone layer and the global climate (UNEP, 2010c; EIA, 2016; Liu *et al*., 2016). A raid conducted by the Spanish state prosecution unit, SERPONA, in July 2012 on a company situated in Las Palmas found that the company was in possession of more than three hundred 1000 kg size cylinders of HCFC-22, as well as the banned 13.6 kg cylinders and refilling equipment. There is also detailed evidence of suspected importation through an ISO tank of HCFC-22 (Environmental Investigation Agency (EIA), 2014). The SERPONA's operation also discovered that another company that was involved had been decanting HCFC-22 into smaller cylinders. Another company was also reported to have been helping to declare HCFC-22 as recycled so that it could be sold on the internal market (EIA, 2014).

Unfortunately, it looks likely that there was an upsurge in the 1990s, where the smuggling of ODS amid mounting evidence of illegal trade of HCFC-22 in both developed and developing nations (Shah *et al.,* 2019). In 2010 in South Carolina, 12 000 canisters of HCFCs valued at more than US$1 million were seized and a company in Miami, Florida was fined for importing of 29 107 cylinders of HCFC-22 worth US$3.9 million between 2007 and 2009 (EIA, 2014). The UNEP (2010c) also reported 160 cylinders of HCFC-22 being seized at the Bangladesh/India border in July 2006 (UNEP, 2010c). Illegal trading in HCFC-22 is undermining all the achievements of the MP.

In spite of there being gas identifiers at all border posts in Zimbabwe, Kunambura (2015) reported an influx of ODS, mainly HCFC-22, through undesignated crossing points. The Government of Zimbabwe is reported to be having a difficult time trying to contain the ODS movement because its borders are not tightly controlled. The Zimbabwe Revenue Authority (ZIMRA), which controls the entry ports, seems not to have the capacity to close the gaps, resulting in a daily influx of the prohibited ODS. In 2013, ZIMRA seized 100 cylinders of HCFC-22 which were illegally imported and falsely declared as ODS-free at Beitbridge border post (Kunambura, 2015).

Unreliable information technology (IT) has also adversely affected online reporting, remote implementation and social networking (UNEP, 2013b). The phase-out of HCFC-22 is proving difficult for Asia and the Pacific countries (UNEP, 2013b). The idiosyncrasies of the Pacific Island countries, remoteness and network deficiencies before 2009, resulted in these countries being marginalised from the MP. The UNEP (2010a) highlighted that HCFC-22 phase-out will pose great challenges in terms of establishing baseline data, as well as fulfilling reduction and final cessation targets. In an effort to phase-out HCFC-22, the UNEP (2010a) reported that countries face challenges in terms of failing to mobilise national stakeholders to rally behind and participate in the process of developing the HCFC-22 phase-out management plan. Yet another hurdle has been the lack of continuity of tenure of ozone officers and customs officials, which has made timeous implementation of activities difficult, as well as wasting much useful time on training new ozone officers (UNEP, 2013b).

The same turnover concerns have been noted by the UNEP (2013b) in relation to the lack of trained technicians in the informal sector; this gives rise to safety-related concerns in the handling of alternative refrigerants, in particular hydrocarbons. UNEP (2011d) estimates put the number of unskilled technicians in Zimbabwe at between 1200 and 1300, working in some 500 service workshops. In addition, there were few semi-skilled technicians in the same sector repairing refrigeration and air-conditioning equipment (*ibid.*).

According to Simmons (1991), technological changes and energy developments resulting from the HCFC-22 phase-out affect both the environment and the health of humanity in ways that are hard to predict. The World Bank (2014) states that HCFC-22 phase-out has come at a huge technological transition cost that has hit small to medium enterprises hard in several developing countries. The accompanying technological changes come at a huge cost or may even render old equipment obsolete. National action related to these matters needs to be integrated with global action and programmes on the technological challenges which seem to be affecting all MP signatories. While exemptions have been given to some parties to the Protocol, the search for alternatives that are viable from the technological and economic perspectives must continue (Andersen *et al.,* 2018).

The parties must also consider the indirect impact of the system's energy consumption pre- and post-HCFC-22 phase-out. An energy efficient system should lead to diminished CO_2 emissions as power is generated. Hence, theoretically, this should in turn reduce global warming. Pointers so far are that developments in technology substantially improve the energy efficiency of some refrigeration applications which do not use HCFC-22, such as air conditioners and centrifugal chillers. In addition to helping the cause of the HCFC-22 phase-out, using these technologies reduces emissions of CO_2 (UNIDO, 2009).

The mission of phasing out HCFC-22 is considered to be a major economic challenge. Velders *et al*. (2009) reported steady linear growth in HCFC-22 consumption since 1998, equating to around 35 000 tonnes per year. Based on 2005 levels, this is an average of about 10% per year (Velders *et al.,* 2009). If this trend is extrapolated, the business as usual scenario suggests that HCFC-22 consumption in 2020 would be double the 2009–2010 value. The UNEP (2010a) reported that China's industrial enterprises are making great efforts to phase out HCFC-22 ahead of time, but progress depends on the economic and technical feasibility.

HCFC-22 usage is ahead of MP schedules; however, economic and the technical feasibility will have a large bearing on the progress. The new rulings on phasing out the ODS in the United States affected the supply and demand for HCFC-22 refrigerants (EPA, 2009). According to Iwanski (2010), the pressures resulting from the previous economic downturn have seen home and business owners investigate how to keep their current systems running efficiently. This could possibly be as a result of the fact that the end users are only considering the economic implication as opposed to the environmental and ozone effects. There is perhaps a need to build awareness with regard to the benefits of the phase-out.

Restrictions on HCFC-22 importation and production could greatly distort the supply and demand of refrigerants and manifest in rising prices (Iwanski, 2010; Ng and Chow, 2014). Gorman (2005) noted investment in the phase-out of HCFC-22, particularly in developing countries, as the current scenario is that they have been turned into a dumping ground by companies that operate in countries that have tighter deadlines for the phase-out of HCFC-22.

2.11.2 Environmental challenges from HCFC-22 phase-out

Ardente *et al*. (2015) highlighted that cooling and freezing appliances represent electric and electronic equipment waste. Refrigeration and air-conditioning units contain several other hazardous substances such as mercury, lead and cadmium. Molina (1996) noted that most of the environmental impacts of these appliances were due to the use of refrigerants such as CFCs and HCFCs. Kundu *et al.* (2016) revealed that once HCFC-22 is removed from service, it will require safe disposal because of its hazardous effect on the environment.

The steep increase in the world population has resulted in a correlated rise in development, urbanisation and consumption. Consequently, this has resulted in an increase in the amount of waste, posing various environmental, social, health and economic ills of vast unknown proportions (Huisman *et al.*, 2008). In as much as development and innovation have been at the centre of improving the lives of humankind, a blind eye has been turned to their effects. In particular, the effects waste generated from productive processes have significantly contributed coupled with lack of governance on environmental issues (Rucevska *et al*, 2015). This is presumably a result of the high costs related to the treatment and disposal of hazardous waste, weak environmental policies, poor implementation of regulations, lack of environmental awareness programmes and the illegal trans-boundary movements of hazardous waste to developing countries, which have become an expanding worldwide concern.

The use of products that contain ODSs is not the only potential source for ODS emission. The current economic situation where many of the second hand, near scrap or substandard electrical products find their markets in developing countries, is exacerbating environmental damage (Hossain *et al*., 2015). This, according to Rucevska *et al.* (2015), has resulted in the development of the term “e-waste”. E-waste is related to waste that includes dumped electrical and electronic hardware, for example refrigerators, televisions, air conditioners and mobile phones, together with the toxic and hazardous materials that many of these products contain (Huisman *et al*, 2008). Examples of hazardous materials are mercury, lead and brominated flame retardants. According to the discussions during the Basel Convention (2011), e-waste in developing countries has significantly contributed to the environmental issues because of the inadequate capacity to manage waste in terms of policy implementation, expertise and resources to name but a few. To avert this harm there is need to develope smarter technologies that do not deplete the ozone layer at the same time reduce environmental impacts. Identifying and classifying electrical and electronic equipment waste is difficult as what is deemed to be a waste to some could still be considered useful by another.

It would logically follow that among HCFCs are refrigerant gases, categorised as e-waste, when the equipment that uses these substances is considered obsolete. Ardente *et al*. (2015) confirmed that cooling and freezing appliances represent electric and electronic equipment waste. Even if experts remove the ODSs prior disposal of equipment, the process still requires safe and thorough procedures to be followed because emission may even occur during that process (Kundu *et al.*, 2016). Molina (1996) noted that most of the environmental impacts of these appliances were due to the use of refrigerants such as HCFCs. Kundu *et al.* (2016) revealed that once HCFC-22 is removed from service, it requires safe disposal because of its hazardous effect on the environment. Old refrigerators and other cooling hardware also contain certain amounts of HCFCs.

2.12 **Case studies of national compliance strategies and HCFC-22 phase-out management systems**

The literature discussed in this section is based on the HCFC-22 phase-out strategies and management systems with specific focus on Botswana and South Africa. The focus of the study is on Botswana but because SA is a major exporter of HCFC-22 to Botswana (South Africa Environmental Affairs, 2010), for example in 2009 it exported 32.6 tonnes of HCFC to Botswana, it is important to explore the phase-out strategies and management systems on these two countries.

2.12.1 A case study of Botswana

2.12.1.1 *Botswana's national response to ozone depletion*

Botswana supported the decision of the 19th meeting of MP parties to adopt an accelerated phase-out of all HCFCs. Botswana therefore joins the global effort in ensuring that ozone depleting concerns, as well as those expressed under the UNFCCC on global warming, are addressed in the phase-out of HCFCs (UNEP, 2015a). HCFC and HFC both have high GWPs and the HCFCs are less stable than the CFCs in the lower atmosphere and therefore have a lower ODP. On the other hand, HFCs have no effect on the ozone layer but do have high GWPs (UNIDO, 2015). The UNEP (2011a) notes that, since the 2nd of March 1992, Botswana has been a signatory to both the VC for the protection of the ozone layer and its associated MP on the substances that deplete the ozone layer, as shown in Table 2.3. Botswana ratified the UNFCCC on 20th of January 1994.

Table 2.3: Ratification of ODSs treaties by Botswana

Treaty	Date of ratification
Vienna Convention	4 December 1991
Montreal Protocol	4 December 1991
London Amendment	13 May 1997
Copenhagen Amendment	13 May 1997
Beijing Amendment	21 February 2013
Montreal Amendment	21 February 2013

Source: UNIDO (2015)

As a signatory to the MP, Botswana is committed to phasing out ODSs. The country initially submitted its HPMP to the 65th meeting, but afterwards withdrew it as it did not have an HCFC licensing system capable of enforcement (UNEP, 2011a; 2016b). At the 25th meeting, a formal request was made to the country by the parties for her to set up a licensing system for ODS importation and exportation as per Article 4B of the MP (decision XXV/15). Botswana informed the 54th meeting of the implementation committee that the non-compliance had been remedied and it had a licensing system in place from December 2014. The implementation committee noted this action in its recommendation 54/7 (UNEP, 2015a).

Botswana solely imports HCFC-22 and this is used entirely to service RAC equipment (UNEP, 2015a). The HCFC-22 consumption for Botswana for the years 2005–2014 is as presented in Table 2.4.

Table 2.4: HCFC-22 consumption and ozone depleting potential in Botswana for period 2005–2014 and 2015 estimates

Period	HCFC-22 Consumption in Metric tonnes	ODP tonnes
2005	56.00	3.08
2006	125.00	6.88
2007	180.00	9.90
2008	230.00	12.65
2009	200.00	11.00
2010	200.00	11.00
2011	198.00	10.89
2012	197.00	10.84
2013	197.00	10.88
2014	190.00	10.45
2015 Baseline	200.00	11.00

Source: UNEP (2011a; 2015a)

Table 2.5: HCFC-22 installed RAC equipment by sector based on UNEP 2010 survey

Type of equipment (refrigerant charge)	No of units	Installed capacity of HCFC-22		Servicing demand	
		Mt	**ODP t**	**Mt**	**ODP t**
Refrigerated transport (3–15 kgs)	100	1.00	0.66	0.50	0.03
Cold and freezer rooms (3–30 kgs)	1640	25.00	1.38	9.00	0.50
Domestic and central ACs (0.6–35 kgs)	224 000	900.00	49.50	190.00	10.45
Other refrigeration equipment (0.5–5 kgs)	500	1.0	0.06	0.50	0.03
Total	**226 240**	**927.00**	**51.00**	**200.00**	**11.00**

Source: UNEP (2011a)

The estimated total number of units of installed RAC HCFC-22-based equipment in Botswana in 2010 was 226 240 units, as shown in Table 2.5. SA supplies all HCFCs used in Botswana as the latter does not produce HCFC. The bulk of this is HCFC-22, the cheapest refrigerant, which constitutes 99.95% of Botswana's consumption and is primarily used in servicing refrigeration and RAC equipment (UNEP, 2015a). UNIDO (2015) reported that the bulk of actively used refrigerants lies in air conditioners (split/unitary) in households, public buildings, business premises and shops. Of these, 60% constitutes domestic refrigeration (air-conditioning unitary/split system), 30% commercial refrigeration and food processing equipment, while 10% constitutes industrial and other equipment (*ibid.*).

UNIDO (2015) noted that equipment using HCFC-22 has a lower energy efficiency ratio (EER) as compared to the alternative refrigerants. HCFC-22 has a higher ODP and GWP which makes it an unfavourable refrigerant because it contributes to the depletion of ozone and causes climate change. It was further noted that the higher the cooling capacity of equipment the lower the EER. The atmosphere-bound emission of HCFC-22 depletes the ozone layer and has also a climate change effect because of its higher GWP. HCFC-22 has a GWP of 1780. This means that the consumption of 100 MT (5.5 ODP) of HCFC-22, if vented into the atmosphere, will contribute to an equivalent of 1 780 000 tonnes of CO_2. This level of emission can have a considerable effect on climate change. The complete phase-out of HCFC-22 will therefore have climate benefits because the HCFC-22 as a GHG that would be emitted into the atmosphere will be lower than the baseline.

Botswana as a net importer of HCFC-22 from SA is unable to effect meaningful policy changes and requisite implementation, since all of SA's policy changes inevitably have an impact on Botswana's consumption of the refrigerant (UNEP, 2011a). The training and adoption of substitute substances for HCFC-22 by Botswana should be benchmarked and designed in compliance with SA's environmental legislation.

Some of the strategies recommended by the MP have been implemented and some are still to be implemented; hence, this part of the literature review will assess the strategies that have been put in place with a focus on the HCFC-22 in Botswana. HCFC-22 remains the type of refrigerant that currently seriously threatens the ozone layer. The assessment will also include the impact of implementing such initiatives.

2.12.1.2 *Botswana's HCFC-22 Phase-out Management System*

In this study the Botswana's phase-out management system is defined by the country's Hydrochlorofluorocarbon phase-out management plan (HPMP) based on the guidelines as agreed under Decision 54/39 at the XIX MOP. Grounded on this decision, Botswana (Article 5) was indebted to develop a framework for total phase-out of HCFC-22 by 2030 (UNEP, 2015a). This was pursuant to Decision XIX/6 reached during the 19th Meeting of the Parties to the MP, whose aim was to accelerate the phase-out of production and consumption of the Hydrochlorofluorocarbons (HCFCs). The main objective of the Botswana HPMP is to obtain both ozone and climate benefits through implementing a unified system for reducing HCFC-22 consumption in the refrigeration sector as well as promotion and adoption of ozone friendly and energy efficient technologies. To that end, a staged approach was adopted, reflecting on the HCFC-22 baseline freeze in 2013, the 10% and 35 % reductions in 2015 and 2020 respectively. Specifically, consumption of CFCs was to be totally phased out before 2010. As part of the country's HPMP, Botswana is expected to assess its HCFC-22 imports and use in various sub-sectors to facilitate its meeting the phase-out obligations (UNIDO, 2015).

2.12.1.3 *Partners in Hydrochlorofluorocarbon phase-out management plan implementation*

The overall lead implementation agency for Botswana's HCFC-22 Phase-Out Management Plan is UNEP, with the UNIDO playing the role of co-operating implementing agency (UNEP, 2015a; UNIDO, 2015). Nationally, the key implementing body of the Botswana HPMP is the Ministry of Environment, Wildlife and Tourism. This ministry houses the NOO, the coordinator of operational activities. The Director of the DMS under the Ministry Environment, Wildlife and Tourism oversees the implementation of the integral phase-out of HCFC-22. A number of other bodies and stakeholders (Figure 2.4) were then established or mandated to see to the implementation of the licensing and quota system, namely, the HCFC licensing committee, the Botswana Unified Revenue Service (BURS) and the Ministry of Trade and

Industry. The HCFC licensing committee is specifically mandated with the implementation of the licensing and quota system. The NOO is the focal point and is mandated with the issuance ODS import and export licences; the BURS, being the customs arm, is responsible for enforcing the quotas at the borders; and the Ministry of Trade and Industry licenses importers and distributors (UNEP, 2015a). The Botswana Refrigeration and Air-Conditioning Association (BRACA) which houses the refrigeration and air-conditioning sector and users of the HCFC-22 is also the important partner in the implementation HPMP (UNEP, 2018a)

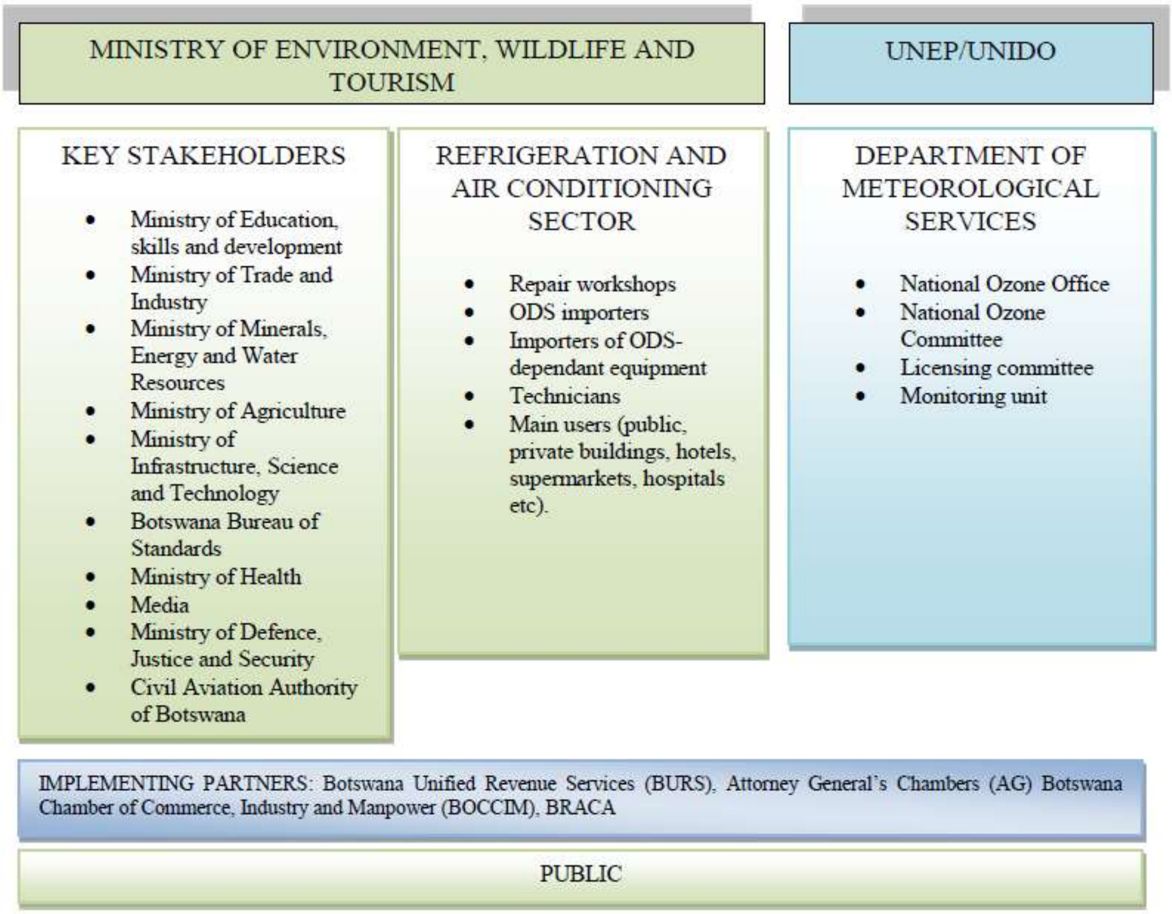


Figure 2.4: Organisational arrangements for the Implementation of the Botswana HPMP

Source: UNIDO (2015)

2.12.1.4 *National Institutional Policy and Legislative Provisions*

The National Meteorological Act of 2014 (GoB, 2014a) and the Ozone Depleting Substance Regulations of 2014 (GoB, 2014b) were established during stage I of the HPMP to manage the phase-out ODS regulation in Botswana. These regulations control the importation and exportation of ODS and equipment and products dependent on ODS. The regulations also control the consumption of HCFC-22 by restricting the importation as well as promoting retrofitting of HCFC-22 -based equipment (UNIDO, 2015a; UNEP, 2018a). To control the importation and consumption of HCFC-22, the licensing system which is quota based was established (UNEP, 2015a). The system has mechanisms that verify facilities handling HCFC-22 and ensure that they have adequate human capacity and equipment to manage the phase-out of HCFC-22 in an environmentally sound manner. For the HPMP to meet its phase-out mandate, it utilise also capacity building, investment and awareness campaigns to enable Botswana to meet its HCFC phase-out obligations (*ibid.*).

2.12.1.5 *HCFC-22 Phase-out strategy in Botswana*

Since ratifying the MP, Botswana has actively implemented ODS phase-out activities. It is this commitment that now sees Botswana developing a plan to phase-out HCFC-22. The Botswana HPMP combines campaigns targeting and based on awareness, regulations, investment and capacity building in order to enable Botswana to fulfil its HCFC-22 phase-out obligations (UNIDO, 2015).

The HPMP project implemented in Stage I (2016–2020) includes the following components: dissemination of regulations related to ODS, customs officer and other law enforcer training programmes, as well as strengthening the customs training curricula, and additional training for technicians who service refrigeration equipment, promoting alternative refrigerant adoption, campaigns to raise awareness, retrofit and recovery activities, providing assistance to end-users and providing tool kits (UNIDO, 2015). Stage II (2022-2030) of the MPMP will undertake activities to phase-out remaining HCFC-22 consumption through promoting the use of environmentally friendly refrigerants.

Consumption of HCFC-22 occurs entirely in the country’s servicing sector (UNEP, 2011a). In its phase-out strategy the country commits to attain the 2015 (10%) and 2020 (35%) HCFC-22 control milestones and articulates a performance-based system for HPMPs whereby funding is released as activities are completed. The goal of the HPMP project in Botswana is to meet the requirements of the 2013 HCFC freeze, the 10% reduction target by 2015 and the 35% reduction target by 2020 as set under the MP (UNIDO, 2015). Complete phase-out is scheduled for 2030, with a service tail to 2040.

Consumption of HCFC in Botswana has been forecasted to grow by 5% in the coming years (UNEP, 2015a), driven by economic development and the growing need for servicing RAC equipment. These figures were expected to peak in 2012 then freeze to baseline in 2013, further decline to 10% by 2015 and then finally reach the 35% reduction target by 2020 and 97.5% reduction by 2030 following the implementation of the HPMP (UNIDO, 2015). Importers and the customs department provide the consumption data, which is then reconciled and reported nationally.

The implementation of HPMP would also encourage the retrofitting of existing HCFC-22-based equipment to HFCs and hydrocarbon based refrigerants. Based on the GWP of these alternative refrigerants, the complete phase-out of HCFC-22 in Botswana would have a positive impact on the climate (UNEP, 2015a). Botswana met its consumption freeze commitments in 2013 and 2014 (UNEP, 2015a; 2018a). Expectations were that the HPMP's first stage would meet the HCFC reduction targets up to 2020, and concentrate on refrigeration and RAC servicing sector (UNEP, 2015a).

2.12.2 A case study of South Africa

2.12.2.1 *South Africa's national response to ozone depletion*

South Africa is the most industrialised country within the African continent as a whole, and is also home to some of the continent's most advanced industries such as the automotive, mining, food distribution, leisure and hospitality, whereby the refrigeration and air-conditioning sector are crucial for the success of these industries (DEA, 2018a).

In South Africa, most companies and the public use products with HCFC-22 refrigerant, the main reason being that it is effective, cost efficient and accessible. However, because of its harm to the ozone layer, HCFC-22 is being phased out in South Africa with an objective of reaching a total ban by 2030 (Ramayia, 2012). South Africa Trade and Industry Chamber (2012) reported that South Africa consented both to the Vienna Convention and the MP in 1990 and to the MP London Amendment in 1992. United Nations' Millennium Development Goals even recognised the need to develop a strategy for protecting the ozone layer, spelling out appropriate mitigatory measures for reducing the depletion of the ozone layer (South Africa Department of Economic and Social Affairs, 2013).

Initially, SA was a Non-Article 5 country and consequently had stringent obligations concerning the phase out of ODSs. However, Article 5 status was granted in 1997 after an application and it was then granted developing country status under all other international agreements as it had a lower per capita consumption of ODSs. Currently, SA remains one of the biggest exporters of products that contain HCFC-22 in Southern Africa (South Africa Trade and Industry Chamber, 2012; Oppelt *et al.*, 2015).

The overarching strategy crafted for the phase-out of HCFC-22 was the HCFC Management Phase-out Plan (South Africa Trade and Industry Chamber, 2012). This strategy was a joint product of the South African government and the UNIDO, setting out the status quo in terms of HCFC consumption in the country, as well as the strategy, actions and support required for effective HCFC-22 phase-out as per the country commitments under the MP. The DEA (2018a) explains that the government in collaboration with industry has made large strides towards carrying out the obligations of the MP on ODSs, subsequently undertaking to meet the milestones in the South African HPMP signed on 11 September 2012 and the provisions of the Regulations Regarding the Phasing-out and Management of Ozone Depleting Substances of 8 May 2014.

2.12.2.2 *South Africa's HCFC-22 phase-out strategy*

In SA, the proposed management plan for HCFC phase-out was published in the *Government Gazette* No. 37621 of 8 May 2014. The DEA (2014) indicated the HCFC reduction required in the course of the phase-out, starting on 1 January 2013. This meant that importation of HCFCs by South African companies from 2015 was expected to decrease progressively until 2030. Ramayia (2012) revealed that stocks of HCFC-22 in SA would decrease, compelling companies to use recycled HCFC-22 or modify their refrigeration, air conditioners or heat pumps completely (UNEP, 2013c).

The assessment of how SA implemented the phase-out of HCFC-22 encompasses the discussion of the legal frameworks and structures available in place, as well as the progress of the efforts to date. As already alluded to previously, a discussion of SA HPMP in relation to Botswana is necessary, as that country exports HCFC-22 to Botswana, hence its HCFC-22 trends are closely tied to those of Botswana.

2.12.2.3 *Existing mechanisms to manage HCFC-22 in South Africa*

Clodic *et al.* (2013) and the DEA Newsletter (undated) explain that currently SA does not manufacture HCFC-22 but imports it from other countries. According to Oppelt *et al.* (2015), in South Africa most ODSs are imported for use in air conditioning, refrigeration, the foam blowing industry and fire extinguishers, and in pre-shipment and quarantine of agricultural commodities. To ensure complete phase-out of HCFC-22, a quota allocation system and an import permit system have been put in place to regulate entry and consumption. The DEA Newsletter (undated) reported that on recommendations by the NOU of the DEA, the ITAC issues a permit for the trading of ODS.

The key pillars of the SA HCFC-22 phase-out strategy, according to the South Africa Trade and Industry Chamber (2012), are the following:

- Legislation on policy and implementation of HCFC supply/demand consumption, import ban, and legislation on substances and equipment that uses HCFC-22.
- Training for recycling, recovery and setting up of HCFC-22 facilities.
- Demonstrations in the refrigeration and aircooling of HCFC-22 replacements of carbon dioxide and hydrocarbons.
- Destruction of ODSs through technical assistance.

2.12.2.4 *South Africa legal framework for managing HCFC-22 phase-out*

The DEA (2014) further stipulated that as of 2014, an individual or entity is prohibited from importing any new or used refrigeration or air-conditioning systems or equipment containing HCFC-22 or any refrigerant or refrigerant blend containing any HCFC. By the same regulations, commencing January 2015, pure HCFC-22 use, or indirect use through other HCFC-22-based refrigerants, was banned, whether for constructing, assembling or installing any new refrigeration or air-conditioning system or equipment. Table 2.6 presents a summary of regulatory measures established during stage I of the HPMP to update the ODS regulation in SA.

Table 2.6: A summary of South Africa regulatory measure

Measure	Date
Quota system for the assignment of import licences for all HCFCs	1 January 2013
A ban on imports of any new or used refrigeration and air-conditioning systems or equipment containing HCFC-22 or any refrigerant or refrigerant blend containing HCFC	1 September 2014
A ban on the use of HCFC-22, either in pure form or as a component of blended refrigerants, in the construction, assembly or installation of any new refrigeration or air-conditioning system or equipment	1 September 2014
Licence/certification required for purchasing refrigerants	1 January 2015

Source: UNEP (2016c)

According to the South Africa Trade and Industry Chamber (2012), the country has fulfilled all its commitments to the international environmental agreements it ratified. Assistance was also extended to importers and exporters so that they could meet internationally accepted standards of environmental management. However, as the country faced unfair trade barriers against its products, it was not able to use international environmental controls in 1999. It was also reported that the country's economic, social and environmental interests were well represented on the global level (*ibid.*).

2.12.2.5 *Training interventions*

The South Africa Trade and Industry Chamber (2012) revealed that service technicians in both the formal and informal sectors would be workshopped on good refrigeration management. Further workshops were held for stakeholder engagement and in order to sensitise stakeholders to the implications and availability of alternative refrigerants (DEA, 2018a). Furthermore, SA developed a customs manual and 95 customs officers received training at seven customs locations. At least one refrigerant identifier has been provided at each training location and additional units have been provided to a compliance-monitoring unit, which undertakes inspections beyond customs premises (UNEP, 2013c; 2016c).

2.12.2.6 *HCFC-22 phase-out implementation progress in South Africa*

Considering the ODPs of the many HCFCs used in SA, the South Africa Trade and Industry Chamber (2012) and the UNEP (2016c) reported that HCFC-22 accounted for about 70% by mass and 51% of ODP in 2010. Bulk break distributors bring in most of the HCFC-22 consumed in South Africa, but there are also direct imports from foreign suppliers as well (DEA, 2018a). In a study conducted by the South Africa Trade and Industry Chamber (2012), it was reported that a sum of 81 companies had import permits for HCFCs in 2010, some of whom were not making use of them. However, the study failed to make meaningful comparisons on the number of registered companies likely to be dealing in these products. This clearly suggests that there could be a greater amount of emission via the unregistered or informal sector.

Table 2.7: HCFC-22 consumption in South Africa (2007–2016)

Period	HCFC-22 consumption in metric tonnes	ODP tonnes
2007	3849.70	211.70
2008	2833.30	155.80
2009	3632.10	199.80
2010	4035.60	222.00
2011	3169.79	174.34
2012	3030.58	166.68
2013	3027.19	166.50
2014	2560.60	140.83
2015	2501.00	137.55
2016	2550.00	140.27

Source: UNEP (2013c; 2016c); UNIDO (2017)

Table 2.7 presents the SA HCFC-22 consumption figures from 2007 to 2016. The government also explained that the reported consumption in 2012 was based on permits issued and not on actual amounts imported; therefore the actual consumption could be lower (UNEP, 2016c).

According to the UNEP (2016c), the government of SA has entrenched a comprehensive set of guidelines for controlling HCFC-22. The HCFC-22 consumption levels reported by SA in 2013, 2014 and 2015 show that the country was complying with what was agreed between the Executive Committee, the government and the MP. The UNEP (2016c) further reported that refrigerant identifiers have been stationed at entry points and customs officers have been trained and equipped with essential practical knowledge and skills to identify HCFCs and HCFC-containing equipment. Substantive events in the refrigeration the servicing sector are expected to begin during the third tranche, which will comprise some demonstrations of low GWP substitutes in supermarkets in the refrigeration servicing sector.

The UNEP (2016c) identified the following activities as being under implementation in SA:

- More laws to restrict supply and demand of HCFCs.

- South African Revenue Service (SARS) continued work with the International Trade and Customs to address modifications required to tariff codes and improve monitoring and reporting.

- Development of a recovery and recycling (RR) feasibility study and implementing RR demonstration activities in two locations; establishing a training curriculum in consultation with industry stakeholders and other government departments; updating codes of practice and regulations related to servicing; running limited projects to demonstrate how to use low-GWP technologies such as CO_2 and ammonia in different applications.

- Continued training of customs officers at remaining land ports in SA; continued information dissemination and awareness activities addressed to the foam and refrigeration servicing sectors; and increasing the number of industry visits to projects under implementation and potential new projects.

- ODS regulation was developed and updated to include important mechanisms for HCFC-22. The public were consulted on the legislation, paving the way for it to be finally approved in March 2014.

The latest development on the road to phasing out ODSs and complying with the MP provisions, says Labacher (2017), is SA's adoption of the MP Kigali Amendment on control and consumption of HFCs during the 28th Meeting of Parties in Kigali, Rwanda, in October 2016.

2.12.2.7 *South Africa's HCFC phase-out milestones*

The DEA (2018a) details notable milestones of the South African phase-out plan. The SA government put in place further control mechanisms in order to curb illegal trade of the controlled substances. Tariff codes for ODS identification from Customs and Excise were in place for use by the DEA NOU when it makes recommendations to ITAC and during the issuance of importation and exportation permits. The control and monitoring of imports/exports into SA is expected to reduce ODS consumption. Also in place from a legal point of view are the Regulations regarding the Phasing-out and Management of Ozone Depleting Substances, Regulation 351 of 8 May 2014. Processes to amend these Regulations are underway and, among other things, include the phase-out or ban of the use of disposable cans (*ibid.*).

A roadshow was held on 14–21 June 2018; this created a platform for deliberating ozone depletion related issues and enabled information sessions for updating information on progress made and new work or initiatives on the horizon (DEA, 2018a). Presentations were made by, among others, NOUs (South Africa (DEA) and Namibia), UNIDO and RAC experts, Registration of Service Technicians, Refrigerant Reclamation (DEA, 2018a). The road show informed industry role players on SA's progress in terms of HCFC Phase-out Management Plans and the milestones reached, and presented alternative non-ODS technologies available in the market, including discussions on the viable use of "traditional" refrigerants such as ammonia. It also provided an opportunity to engage stakeholders on the challenges and economic viability of refrigerant recovery, recycling and reclamation, and bridged the knowledge gap, as well as encouraging a dialogue between industry, technical experts, government, academia and other related stakeholders. Ozone protection authorities also engaged stakeholders in the safe handling of refrigerants and communicated the DEA's intentions to register RAC informal servicing technicians. Overall, the HPMP Road show strengthened collaboration among government departments, academia and industry role players towards a successful implementation of the MP obligations.

2.12.2.8 *Challenges to phase-out of ODS efforts in South Africa*

Acceptance of the idea of HCFC-22-phase-out has been slow with some players in the industry and this has resulted in the ongoing use of HCFCs. Despite the increase in volume of HFC-134a equipment, the fact that HCFC-22 compressors remain cheaper than HFC compressors continues to hinder the phase-out of HCFCs (Brophy, 2016). Current systems for identifying and classifying HCFCs and HCFC-based equipment might require improvement for their more effective control. Considerable effort is necessary to fully engage refrigeration and air-conditioning sector end user stakeholders to assist (DEA, 2018a). Substantial short- to medium-term HCFC-22 demand will probably continue in the industrial refrigeration sector. These factors have limited the adoption of HFC-134a in some process cooling applications which have seen new systems being installed (South Africa Trade and Industry Chamber, 2012).

Labacher (2017) posits that SA's obligation to significantly phase-out ODS in accordance with the MP and the Kigali Amendment means that the mining industry will have to comply in order to keep its green status. This will have serious implications for the operation of mining companies that are the backbone of the economy. The country also has a very long land border, which facilitates illegal movements of a variety of air conditioning and refrigeration equipment operating with HCFC-22 greater than CFC-12 (Government of the Republic South Africa (GRSA), 2011).

The number of members of trade associations has been declining, a development attributed to the weak economy and perceptions of lack of value in membership (South Africa Trade and Industry Chamber, 2012; African Development Bank, 2019). SA is a significant emitter of GHG so it is extremely vulnerable to climate change. Extreme weather conditions, such as droughts could have severe effects in a country where water is already scarce and droughts are expected to occur more frequently (GRSA, 2011; Carbon Brief, 2018). According to Ramayia (2012), a decrease in production of HCFC-22 will increase the difficulty in obtaining it, pushing prices higher as was the case with the European and American industry before HCFC-22 was phased out there. The DEA (2018a) also noted the challenges raised by stakeholders (both industry and government). Firstly, the annual reporting requirements and time frames were said to be hectic. The government also expressed concern with the competence and compliance of RAC Informal Service Technicians. The UNEP (2012b) says skilled technicians who do servicing, installation or repair of refrigerators and air conditioners number above 5000. Yet of these, only 986 are legally registered. Similarly, out of more than 1500 service contractors employing at least two skilled technicians, only 56 belong to the Refrigeration and Air-Conditioning Contractors Association.

2.13 **Conclusion**

Ozone depletion continues to be a worldwide issue. The MP and other international agreements have gone a long way to safeguard the ozone layer. Nevertheless, for this to be a long-lasting success everyone should be part of the solution, where individual efforts are put together for an environmental change and are faithful to the collective resolutions of the global community of nations. Much work remains to be done on the implementation front. Notably, though, most of the literature reviewed is based on theoretical affirmation, with few sources having empirical backing. This highlights a very big gap that needs to be closed by undertaking more empirical studies in the field in terms of how to effectively contain the ozone depletion menace. It is this gap that this study seeks to close: to provide an empirical, evidence-based examination of the challenges, complexities, and successes and failures where applicable, of implementing the provisions of the MP and its amendments at country level, in particular in a developing country context. By examining not just the HPMP of Botswana but also drawing parallels and contrasts with the experiences of both developing and developed countries, the study seeks to put the status of mitigation efforts against ozone depletion in their proper, factual context, hopefully then directing attention to real as opposed to imagined issues surrounding HCFC-22 phase-out.

CHAPTER 3

STUDY DESIGN AND METHODOLOGY

3.1 Research design

A research design is defined as a master plan for a research project, specifying main procedures and methods to be undertaken, including methods for collecting and analysing data employed and addressing the specific aims and objectives of the study (Creswell and Creswell, 2017; McKim, 2017; Kumar, 2019). The study focuses on an evaluation of the phase out of HCFC-22 management systems and its environmental implications in Botswana. The study design which was adopted was a mixed method approach. This approach combines both quantitative and qualitative approaches in a single study where data collection is simultaneously and sequentially collected (McKim, 2017). The mixed method approach was used to expand on quantitative results using qualitative data. Both qualitative and quantitative approaches assisted the researcher to lay out the methodologies, data collection and data analysis necessary to carry out the study.

In this study, the qualitative approach consisted of interviewing the NOO from the Department of Meteorological Services (DMS), importers of HCFC-22 and customs officers from BURS. The respondents were interviewed to find out their opinions on the management of HCFC-22 phase-out. The use of a qualitative approach enabled the researcher to collect a rich set of data that could not be obtained using a quantitative approach alone. The qualitative approach also included site visits/walks through importer companies to access and collect basic data on the organisation as well as topics related to the management of HCFC-22 phase-out. Hot spots, warehouses/HCFC-22 storage places, unauthorised entrances and waste storage places were observed. An observation sheet was used to record observed data (Appendix C). The qualitative approach, which is subjective, made use mainly of language and descriptions.

Quantitative research refers to the systematic empirical investigation of social phenomena through statistical, mathematical or computational techniques (Moutinho and Huarng, 2013). The measurement procedure is fundamental to quantitative research because it gives the vital connection between empirical observation and the mathematical expression of a quantitative relationship. Quantitative research methods attempt to give answers to questions about relationships between measurable variables (*ibid*.). They also make it possible to explain causation among variables, generalise research and predict relationships between variables.

The measured variable was the amount of HCFC-22 imported by companies. The quantitative approach consisted of ascertaining precise measurements of the amount of HCFC-22 imported per year by licensed companies, and the amount of HCFC-22 imported recorded by the BURS and the DMS. This approach was also used to find the number of trained customs officers and technicians. A measurement sheet was used to record HCFC-22 imported (Appendix C). The quantitative approach provided the basis for objective measurement and observation independent of the research through the administration of research instruments for data collection regarding the management plan for phasing out HCFC-22. The quantitative approach tended to be statistical and objective, involving the use of numbers (Moutinho and Huarng, 2013).

3.2 **Study setting**

The preliminary survey carried out by the researcher revealed that there are ten (N= 10) private companies in Botswana registered with the DMS which have permits that allow them to import ODS. Nine of these companies are based in Gaborone 24° 39' 17.39" S 25° 54' 26.39" E and one is in Francistown 21° 10' 15.00" S 27° 30' 26.99" E. Gaborone is situated 420 kilometres from Francistown. The nine companies in Gaborone are privately owned and operate under different management and conditions. The research considered all the companies that are registered and have permits to import ODSs because the population of companies is small, including all (N= 10) of them in the study provided more accurate data and increased the confidence interval in the survey results. Data collection using a census method allowed the researcher to study the phase-out management systems of HCFC-22 intensively and provided a true measure of the population.

The study included the NOU which falls under the DMS. This is the key department responsible for monitoring and managing the country’s programmes and activities that deal with substances that deplete the ozone layer in order to comply with the MP. The NOU is supported by the MLF through the instructional strengthening project. The NOU is responsible for the management of the country’s compliance strategy, collecting and reporting ODS data and monitoring and facilitating the country’s compliance plans as agreed by the MLF. The department is also responsible for developing and implementing legislation and policies, coordinating with other ministries, interacting with industry and the public, and conducting public awareness activities. The NOU is led by an NOO, assistant officers and other staff members. The researcher worked with two members of this department as a research team during the research period as indicated in Appendix D. The main branch of the NOU is in Gaborone and there is another branch in Francistown.

The setting of the study included twenty (n=20) entry points into Botswana. As stated in the literature, most of HCFC-22 used in Botswana is imported from SA and China; therefore all (15) entry ports from South Africa to Botswana were considered (entry ports marked 1–15 in Figure 3.1). Most of the HCFCs are imported via land-based ports. These included five main entry ports (Tlokweng Gates, Pioneer Border Gate, Ramathlabana, Ramotswa and Martin's Drift), and ten minor entry ports (Zanzibar, Pitsane Molopo, Platjan, Sekwane, Pont Drift, Parr's Halt, Bray, Makopong, McCarthy's Rest and Middlepits). Three major entry ports in Namibia (Mamuno), Zambia (Kazungula Ferry) and Zimbabwe (Ramokgwebana) (entry ports marked 16, 19 and 23 respectively, as shown in Figure 3.1) and two main airports in Botswana (Seretse Khama International Airport (Gaborone) and Francistown Airport) were also considered. BURS operate at 24 entry ports (as shown on entry ports marked 1-24 in Figure 3.1) and four airports. These entry ports operate under different conditions; major entry ports are open from 06:00–22:00 and others from 06:00–24:00, while the operation times of minor entry ports range from 06:00-16:00, 07:00-16:00, 08:00-18:00 and 08:00-1400.

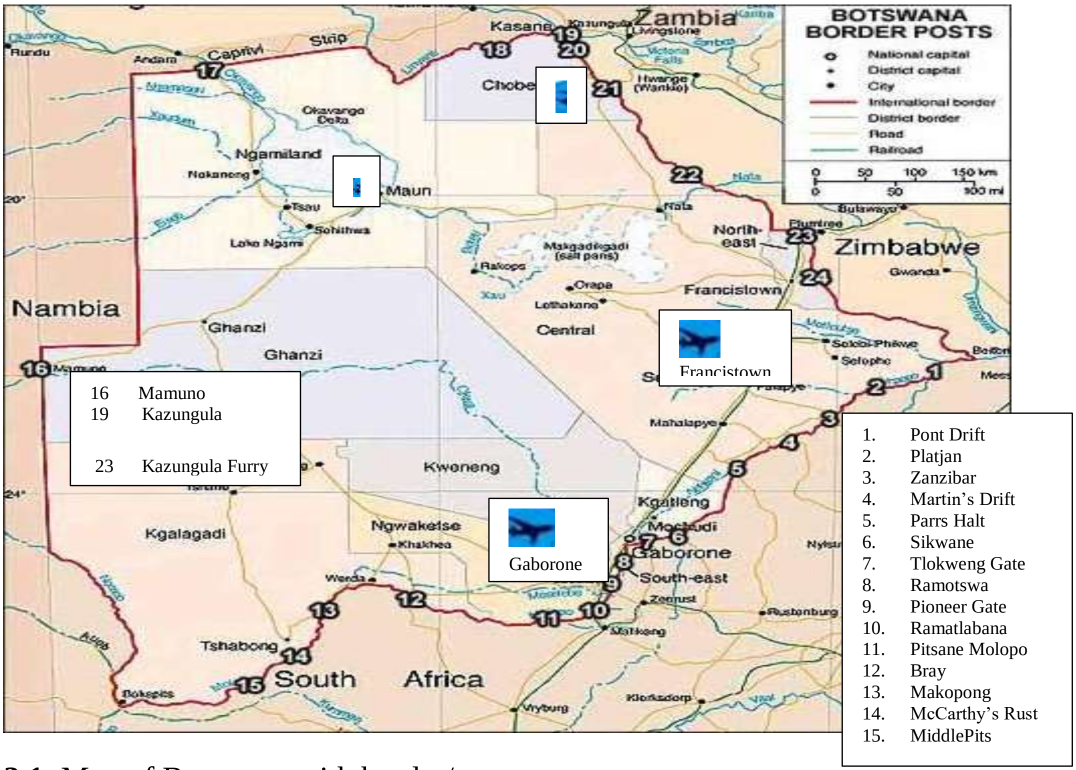


Figure 3.1: Map of Botswana with border/entry ports
Source**:** Ezilon (2009)

The researcher used a purposive sampling technique to select a sample of entry points. A purposive sampling method is a non-probability sampling method which allowed the researcher to choose a sample with the purpose of including a predetermined group of entry ports/border post of interest. Since most HCFC-22 is imported from SA, the researcher chose to use the total population of entry ports (N=15) to SA. It is expected that studying all SA entry ports will reveal insights in the importation of HCFC-22. The purposive sampling technique comprises a non-probability approach; hence, it is subject to bias and error.

3.3 The population, sample and sampling procedures

3.3.1 Study population

The target population included stakeholders involved in the importation, regulation (Ministry of Environment, Wildlife and Tourism and the Department of Meteorological Services under the NOU), trading and consumption (licensed companies and consumers) of HCFC-22 refrigerants in Botswana and monitoring of importation of HCFC-22 (customs/BURS).

By virtue of their numbers all licensed companies that import ODSs were included in the study. Therefore, the entire population of companies was considered in the study. The sampling framework comprised the ten (N=10) companies whose names were obtained from the NOU.

The study also included two experts, the national ozone officer and the assistant national ozone officer from the DMS responsible for monitoring ODS activities who fall under the NOU (Appendix D).

Since most of the HCFC-22 is imported from SA, all (N= 15) entry ports with SA were included into the sample. The sample also included two major airports and three main entry ports to neighbouring countries (Namibia, Zambia and Zimbabwe). Therefore, twenty (n=20) entry ports were used in this study as shown on Figure 3.1. To select the sample of entry ports, the researcher used purposive sampling which is a non-probability sampling technique where the researcher chose a sample with the purpose of including a predetermined group of entry ports of interest. The list of names of entry ports from which the sampling framework was developed were obtained from BURS in Gaborone.

3.3.2 Sample and sampling procedures

Owing to the nature of the study and the phenomena which required in-depth technical knowledge, a census and purposive sampling techniques were adopted. The respondent population included representatives from the ten companies licensed to import HCFC-22, representatives from DMS working closely with the NOO, customs officers from selected entry ports and HCFC-22 consumers from the licensed companies. Purposive sampling was used because it allowed the researcher to collect data from subjects of interest, focusing on the characteristics of the population that enabled it to answer the research question. Probability proportional to size (PPS) was used to select the sample of 220 respondents, as shown in Table 3.1. This method allows respondents from each stratum to be equally represented. A larger stratum allows more samples to be taken.

A total of 220 questionnaires were distributed to respondents. Each of the categories of respondents had a specific questionnaire designed for them. However, only 159 of the returned questionnaires were usable. Subsequently, the researcher considered those questionnaires which were at least 75% completed and the rest of the partially completed questionnaires were excluded. Stratification ensured representation of each category of respondents and produced improved estimators with less variation. A list of customs officers at the selected entry ports was obtained from BURS headquarters in Gaborone. A random sample of 10% of customs officers was selected at each entry port. This resulted in a sample size of 70 customs officers at the 20 entry ports.

The Botswana ODS Regulation requires that importers of ODSs should keep a record of names and addresses of entities to whom the ODSs have been supplied. Therefore, the researcher obtained a list of names of HCFC-22 consumers from the ten companies that import HCFC-22 to Botswana. Accordingly, a sample of 100 end users of HCFC-22, comprising 10% of the population, was randomly selected from each company.

A random sample of 35 employees from the DMS was decided, constituting 10% of the total population of DMS employees. According to Polit and Beck (2010), in quantitative studies large samples are recommended. The larger the sample the more representative of the population it will be, and the smaller the chances of producing less accurate estimates. The study population may be summarised as follows:

Table 3.1: Study population

Stakeholder	Target population	Study population
Licensed companies	10	9
DMS/Ministry of Environment	35	25
End-user consumers	100	65
Customs officers	70	60
TOTAL	**220**	**159**

3.4 Research instruments

A mixed methodology allows for the manipulation of various data gathering instruments which include questionnaires (Appendix A), interview guides (Appendix B), field observation (Appendix C4) and review of records. Reliability is understood as the extent to which a chosen data gathering instrument may be repeated under similar condition (Zohrabi, 2013; Judea, 2015). The reliability of the coded data on the questionnaire was tested using Cronbach's alpha (section 3.4). Stopher (2012) states that in research, bias can result from errors that are encountered with during measurement, especially when measuring instruments are not accurate; then the sample is not a true representative of the population and is subject to procedural bias. Accordingly, measures were taken to minimise bias as well as sampling and non-sampling errors. The large sample size of respondents and the actual population size of licensed companies were considered (Appendix E). To avoid errors, the target population and the sample frame that matches it were considered at the design stage, while measurement errors, processing errors and over-coverage were amended by data editing.

Reliability is an important concept in research because it can be used to minimise errors during the analysis of responses to questionnaires (Mohajan, 2017). Reliability also deals with the dependability, consistency and replicability of the results of any research (Neuman, 2012; Chakrabartty, 2013). Cronbach's alpha was used to test the reliability of the questionnaires. Ader and Mellenbergh (1999) and Vandenplas *et al.* (2015) note three types of non-respondents which include the non-contactable, the refusers and the not able. In this study, one company was not able to participate because the management was not willing to share the company's information; hence, the researcher was unable to collect data from the company. Various methods were employed to overcome nonresponse from respondents. Since the visits took place every three months, follow-up visits were made to try and include respondents who did not participate on the first visit. For respondents with language problems, the local language (Setswana) and terms were used to overcome the barrier. However, as there were non-respondents from BURS and DMS/Ministry of Environment, other sampling units based on the replacement criteria were selected.

3.4.1 Questionnaires

Questionnaires in the form of structured, semi-structured and unstructured formats were used for primary data collection from the study population. These were designed using simple language and mutually exclusive and exhaustive response categories. The use of vague and emotionally loaded words was avoided, as were double-barrelled, complex, incomplete and ambiguous questions (Pallant, 2011; Stopher, 2012; Rowley, 2014). In this study, questionnaires were used to measure respondents' views, opinions and perceptions (Stopher, 2012), mainly in regard to the HCFC-22 phase-out management plan in terms of product awareness, consumption, disposal methods, reduction/phase-out plan and challenges associated with the HCFC-22 phase-out. The questionnaire was divided into three sections. Section A dealt with demographic data of respondents deemed significant for the analysis of the HCFC-22 phase-out strategies. These data included personal variables such as level of education, years of service provision and whether they were in management or not. Section B addressed respondents' awareness and knowledge of HCFC-22 and its phase-out strategies. The variables dealt with in this section were used to evaluate the stakeholders' level of HCFC-22 awareness and phase-out plans. Section C addresses the management of HCFC-22 phase-out by different stakeholders, which is an integral component the HCFC-22 phase-out strategy. The target respondents were HCFC-22 retail consumer companies, HCFC-22 end-user consumers and customs officers. Two sessions were held; during the first session respondents were allowed to complete section A and B, while section C was completed after a break to ensure that respondents were comfortable. Respondents decided when to continue with the session and also decided on the length of the break.

Different questioning techniques which include binary questions (yes/no response), Likert scales and open-ended questions may be applied in questionnaires (Norman, 2010; Robbins and Heiberger 2011). Questions involving Likert-type scales ask respondents to rate a particular statement by selecting one of these following responses: strongly agree, somewhat agree, agree, neutral, disagree, somewhat disagree, or strongly disagree (Du Plooy, 2009; Boone and Boone, 2012; Harpe, 2015).

Questionnaires were also administered on a voluntary basis and on condition of anonymity through pick and drop at selected retail companies, consumers who had an account with the companies selected in this study and randomly selected customs officers at the purposefully selected Botswana border posts/entry ports. The researcher coordinated and supervised the distributed questionnaires at selected border/entry ports and companies and made sure that they were completed correctly.

3.4.2 Semi-structured interviews

Sekaran (2009) and Jamshed (2014) maintain that semi-structured interviews are less formal and structured, allowing room to study and understand the phenomenon in greater detail than in structured interviews. Key informants were interviewed in this study. Kumar (1989) notes in this regard that key informant interviews entail interviewing knowledgeable persons who can provide the required information, opinions and insights on a particular subject. According to Chambers (1992), the selection of key informants involves examining who the experts are. Hence, the following key informants were identified and interviewed: the facility representatives from each of the nine companies, the National Ozone Officer (NOO) from the meteorological office and the principal customs officer from BURS. A specific interview guide was designed for each subject to be interviewed (Appendix B). Consent was obtained and appointments were made prior to the subjects being interviewed.

3.4.3 HCFC-22 quantification and field observations

Data collected during this study formed the basis for describing and evaluating the management of HCFC-22 phase-out. In research, measurements are often regarded as being the basis of all scientific inquiry, and measurement techniques and strategies are essential components of research methodology (Terrell, 2015). Welman *et al*. (2006) add that measurements serve as a bridge between concepts and theories as well as scientific research and its application. Aspects which were measured were the quantities of HCFC-22 refrigerant imported and consumed annually in Botswana. Information on HCFC-22 quantities was obtained from the selected companies which are authorised to import HCFC-22 into Botswana. Following the first visit, information on the quantities of HCFC-22 was obtained from each company every three months for one year. Quantities for the amount of HCFC-22 imported into Botswana were also obtained from BURS. Customs officers at all Botswana border posts have been trained to identify, quantify and prevent the illegal trade of ODS (see Appendix C1). Visits to collect quantities of HCFC-22 at border posts were also made quarterly. The researcher calculated the amount of HCFC-22 in gas emitters/equipment imported by each company. These measurements enabled the researcher to quantify or qualify abstracts and variables needed for statistical analysis (Creswell, 2014). A measurement sheet was used to record the data obtained. This is included in the thesis as Appendix C1 and was used to record the quantities of HCFC-22 imported into Botswana since the start of the HCFC-22 phase-out in 2009. Data collected from the NOU helped to evaluate the phase-out trend of HCFC-22.

Observations are carried out by the researcher as a participant observer, generating meaning as he/she interacts with the study phenomenon (Polit and Beck, 2008). The researcher combined observation with questionnaires and interviews to enable the collection of relatively objective first-hand data. Pandey and Pandey (2015) highlight that observation is the most commonly used data collection method in evaluation research. Accordingly, types of equipment containing HCFC-22 refrigerant in selected companies, their stacking and storage practices, use of leak detectors and other phase-out management practices were observed (Appendix G4).

During the observation process, a checklist with specific items to be observed was used (Appendix C4). The advantage of a checklist, according to Zohrabi (2013), is that it is detailed and the researcher can easily tick the most appropriate box according to her/his observation. Data collection using observations helps to complement information collected through interviews and questionnaires (Jamshed, 2014).

3.4.4 Secondary data review

Johnston (2014) noted that a secondary data review is the review of information that was collected by someone else for another primary purpose. The review of secondary data was carried out simultaneously with participant observation, using the best practice approach of a literature review (Van Maanen, 2007), as well as strategies based on the National Meteorological Act of 2014 (GoB, 2014a), Ozone Depleting Substance Regulations of 2014 (GoB, 2014b); Botswana Strategy for Waste Management of 1998 (GoB, 1998) and the Botswana HPMP. Data on the past and current consumption and management of HCFC-22 phase-out was obtained from the DMS. The use of secondary data provides a feasible alternative to researchers with limited time and resources (Johnston, 2014; Mohajan, 2017). Secondary data review further included a review of previously collected data on the phase out of HCFC-22. To enable a comparison of Botswana and South African HCFC-22 phase-out strategies, parts of SA's ODS policy and regulatory frameworks were examined including SA's HPMP, the Air Quality Act 39 of 2004 which introduced import and export of ODS, the DEA regulation 33395 of 2011 which established a quota system to restrict HCFC-22 imports, and DEA reports on HCFC-22 phase-out. The MP 2016 handbook on substances that deplete the ozone layer was also used for reviewing secondary data.

3.5 **Pilot study**

A pilot study was carried out to familiarise the researcher in the study and to give insight into the phenomenon. A pilot survey enables errors to be corrected with few costs (In, 2017; Resnick, 2015). In this study the pilot study was essential to improve the effectiveness and validity of the research questions before the actual data collection began. Heravi *et al.* (2015) argued that although applying a pilot study does not guarantee success in the main study, it does improve the probability of success. The piloting of questionnaires was carried out with three participants who met the following selection criteria: customs officers, end-user consumers and meteorological department officers. Pilot study and pre-tests were procedurally carried out to test and refine the study before the actual data collection (Stopher, 2012; In, 2017). Pilot testing allows for the adjustment and correction of the questionnaire thereby improving its reliability and validity (Resnick, 2015). After the pre-testing, the responses were discussed and sections which were not clear were clarified. The completed pre-test questionnaires were included in the final data set as no significant changes were made. Data from the pilot study was consistent with results.

3.6 Validity and reliability of the study

Validity refers to the conceptual and scientific soundness of a research study (Pallant, 2011; Godwill, 2015). Zohrabi (2013) and Pandey and Pandey (2015) add that the validity of the study relates to how the research precisely assesses a particular concept that the researcher attempts to measure. Significant measures were considered to ensure that the data collected were of good quality. Issues of external validity were considered in this study. Athanasou *et al.* (2012) argued in this regard that external validity to some extent partially justifies how findings can be generalised beyond the study sample to other populations, settings and circumstances. To achieve this, certain measures need to be put in place to ensure that the research is done appropriately such that valid results and conclusions are made (Graustein, 2014; Pandey and Pandey, 2015).

Factor analysis was used to test the validity of the questions for the constructs of product knowledge and HCFC-22 phase-out awareness. Bandalos and Finney (2018) described factor analysis as a method of showing the covariation among a set of observed variables as a function of one or more latent constructs. The validity of the constructs was analysed by extracting the first two components that measured 73% of the variation. Table 3.2 presents the results of the factor analysis for the constructs of product knowledge and HCFC-22 phase-out awareness. Most questions for the construct "Phase-out awareness" were highly correlated with factor component 1. On the other hand, questions for the construct "Product knowledge" were highly correlated with factor component 2. This means that the question items used to measure the constructs "HCFC-22 phase-out awareness" and "Product knowledge" measured what they intended to measure.

Table 3.2: Product knowledge and HCFC-22 phase-out awareness component matrix

Question	Component 1	Component 2
PHASEOUTAWARE_8	0.705	
PHASEOUTAWARE_1	0.608	0.248
PDCTKNOW_3	-0.570	0.169
PHASEOUTAWARE_7	0.561	-0.419
PHASEOUTAWARE_3	0.546	
PHASEOUTAWARE_4	0.494	
PHASEOUTAWARE_2	0.464	0.345
PHASEOUTAWARE_5	-0.456	
PDCTKNOW_10	0.110	0.448
PHASEOUTAWARE_10	0.395	
PHASEOUTAWARE_9	0.386	-0.279
PDCTKNOW_1		0.379
PDCTKNOW_2		0.368
PDCTKNOW_8		0.322
PDCTKNOW_5		0.269
PHASEOUTAWARE_6	-0.748	-0.122
PDCTKNOW_9	0.303	0.554
PDCTKNOW_4	-0.389	0.519
PDCTKNOW_6		0.456
PDCTKNOW_7		0.392
PDCTKNOW_11	0.102	0.133

Factor analysis was also used to determine the validity of the questions used to measure the construct “DMS compliance with the National Meteorological Act, 2014 and HPMP”. A maximum of two components, accounting for 68% of the variation, were extracted. The results are shown in Table 3.3. Seventeen out of the 20 questions used to measure the construct “Meteorology’s level of compliance” were highly correlated with the first component. Only three question items (questions 16, 17 and 20) were weakly correlated with first component. This shows that most questions measured the construct “Meteorology’s level of compliance”. The ideal situation would be to remove the questions that seemed not to measure the construct. However, owing to the relevance of the questions for the investigation, it was decided not to remove them from the questionnaire.

Table 3.3: DMS compliance with National Meteorological Act, 2014 and HPMP component matrix

Question	Component 1	Component 2
COMPLIANCE_1	0.678	0.320
COMPLIANCE_2	0.694	
COMPLIANCE_3	0.622	0.478
COMPLIANCE_4	0.600	0.182
COMPLIANCE_5	0.593	0.143
COMPLIANCE_6	-0.444	0.277
COMPLIANCE_7	0.323	-0.101
COMPLIANCE_8	0.409	-0.192
COMPLIANCE_9	0.440	0.155
COMPLIANCE_10	-0.395	0.193
COMPLIANCE_11	0.225	0.128
COMPLIANCE_12	0.124	0.734
COMPLIANCE_13	0.52	-0.249
COMPLIANCE_14	-0.645	
COMPLIANCE_15	0.362	0.116
COMPLIANCE_16	-0.243	0.802
COMPLIANCE_17	-0.101	-0.476
COMPLIANCE_18	0.844	
COMPLIANCE_19	0.595	0.488
COMPLIANCE_20		0.514

Finally, factor analysis was also conducted on the constructs "Economic impacts of the HCFC-22 phase-out", "Environmental impacts HCFC-22 of the phase-out" and "Social impact of HCFC-22 phase-out". The first three components that accounted for 65% of the variation were extracted. Generally, the results in Table 3.4 show that component 1 is correlated with the question items that measure the "Impact of phase-out on the environment". Factor component 2 is correlated with most question items that measure "Economic impact of the phase-out". Lastly, factor component 3 is correlated with question items that measure "social impact of the phase out". This means that the instrument used to measure the items was generally valid.

Table 3.4: Economic, environmental and social impacts of HCFC-22 phase-out component matrix

Question	Component		
	1	2	3
ENVN_8	0.708	-0.269	
ENVN_3	0.656	0.151	-0.128
ENVN_1	0.633	0.375	
ENVN_6	0.621	0.416	-0.12
ENVN_2	-0.485	0.444	-0.128
ENVN_5	0.449		0.154
ENVN_4	0.434	-0.179	0.225
ECON_7	-0.38		-0.154
ECON_8	-0.365	-0.176	
ENVN_12	-0.326		
ECON_9	-0.299	-0.656	0.21
ECON_5	-0.374	0.645	0.216
ECON_3	-0.214	-0.619	0.117
SOC_5		0.521	0.126
ENVN_11	-0.3	-0.404	0.187
ENVN_10	0.278	0.374	0.256
ECON_6		0.364	0.344
ECON_2		0.231	
ECON_4		0.149	
SOC_4	-0.289	0.121	0.739
ECON_4		-0.134	0.699
ECON_1	0.164	-0.24	-0.613
ENV_7	0.304	-0.157	0.591
SOC_1			-0.284
SOC_2	-0.23		0.275
SOC_3	0.133	-0.13	-0.168

In this study, the researcher created a data entry template in Microsoft Excel, and the Statistical Package for Social Scientists (SPSS 24.0) and R v 3.5.1 package (R Foundation Core Team, 2018) were used for capturing data from completed questionnaires. Some responses on the questionnaires were pre-coded, while others were post-coded. Stopher (2012) and Zull (2016) propose that coding is a stage where responses in the questionnaire are changed to codes that allow a computer-based analysis to be undertaken. The process of data capturing started soon after the completed questionnaires had been double checked for errors and completeness. The key data from there interviews were also coded, organised and analysed in terms of the completed checklists in Microsoft Excel.

On completion of the coding process, the reliability of the coded data was tested using Cronbach's alpha – a measure of reliability. Mohajan (2017) notes that in research, reliability is concerned with the dependability, replicability and consistency of research results. The Likert scale statements on HCFC-22 phase-out, product knowledge, awareness and the extent of compliance of the Department of Meteorology services with the Meteorological Act of 2014 were checked for internal consistency using Cronbach's alpha. Cronbach's alpha measures reliability by establishing the consistency with which respondents answered the items on the measure (Bryman and Hardy, 2009; Du Plooy, 2009; Heravi *et al.,* 2015). Pallant (2011) refers the scale's internal reliability as the degree to which the scale items hang together. According to Mohajan (2017), reliability coefficients range between 0 and 1, with higher coefficients specifying higher levels of reliability. Items with a coefficient value equal to or greater than 0.7 are considered to be consistent, between 0.7 and 0.8 is acceptable, while values of the alpha (α) greater than 0.8 are acceptable and less than 0.7 is considered to be poor (Sekaran and Bougie, 2009; Pallant, 2011; Zull, 2016). Table 3.5 presents the reliability coefficient for this study.

Table 3.5: Reliability test (Cronbach's alpha)

Alpha (α)	Variable	Items on Likert	Number of respondents
0.76	Compliance with National Meteorological Act 2014 and HPMP	20	25
0.81	HCFC-22 phase-out awareness	10	159
0.79	Product knowledge	11	159
0.77	Economic impacts of HCFC-22 phase-out	9	94
0.77	Environmental impacts of HCFC-22 phase-out	12	94
0.76	Social impacts of HCFC-22 phase-out	5	94

The results show that each variable is reliable and consistent as the alpha coefficient is more than 0.76.

3.7 Data analysis

Data analysis entails the use of statistical methods to describe and interpret the results (Godwill, 2015). Table 3.6 gives a summary of the data analysis methods used in this study. The analytical methods employed are basically categorised as descriptive statistics and are discussed in the subsequent subsection.

Table 3.6: Summary of analytical methods employed for each objective

Research question	Research objective	Analytical method
What level of awareness and product knowledge do stakeholders in the regulatory, importation and distribution of HCFC-22 in Botswana have?	To assess the levels of awareness and product knowledge of service and regulatory stakeholders in the importation and distribution of HCFC-22 in Botswana	Univariate analysis • Percentages • Bar charts • Means • Median • Standard deviation • ANOVA test • Tukey's HD test • Box plots • Tables
How does Botswana manage the phase-out of HCFC-22?	To examine the Botswana's HCFC-22 phase-out management system	Univariate analysis • Secondary data analysis • Percentages
To what extent is Botswana compliant with the Montreal Protocol resolutions on the monitoring, consumption and phasing out of HCFC-22?	To evaluate the level of compliance of Botswana to the Montreal Protocol resolutions on the monitoring, consumption and phasing out of HCFC-22	Univariate analysis • Percentages • Line graph • Likert graph • Tables • Bar harts
What milestones has Botswana attained in the phase out of HCFC-22 pursuant to the MP?	To evaluate the milestones in HCFC-22 phase-out trend pursuant to the MP	Univariate analysis • Percentages • Line graphs • Tables
What are the social, economic and environmental implications of phasing out HCFC-22?	To examine the economic, social, and environmental implications of phasing out HCFC-22	Univariate analysis • Tables • Bar graphs • Likert graphs
How similar and/or disparate are South Africa's and Botswana's HCFC-22 phase-out management strategies and implementation based on the Montreal Protocol resolutions?	To compare and contrast South Africa's and Botswana's HCFC-22 phase-out management strategies and implementation based on the Montreal Protocol resolutions	Univariate analysis • Secondary data analysis • Percentages

3.7.1 Descriptive statistics

According to Pallant (2011), descriptive statistics are used to define the characteristics of the sample, address specific research questions and check for assumption violation. Loeb *et al.* (2017) added that descriptive analysis plays a pivotal role in different aspects of research and is part of almost every empirical report. The main purpose of undertaking descriptive statistics is to create relationships and patterns and to describe variables in a clear and understandable manner (Kaushik and Mathur, 2014; Kemp *et al.*, 2018).

Ader and Mallenbergh (1999) posit that structures and patterns in statistics are revealed through the distribution of single variables and by the relationship between the variables. Therefore, to achieve research objectives, descriptive analysis provides summaries and displays a general picture of the data (Coe *et al.,* 2002; Kemp *et al.,* 2018). In this study, the preliminary data analysis and descriptive statistics were accomplished using Microsoft Excel, SPSS 24.0 package and R 3.5.1. The descriptive statistics included univariate analysis, which involved analysing data for single variables separately (Cramer, 1994). These include percentages, frequencies, proportions, graphs, charts, central tendencies and variations (Kaushik and Mathur, 2014; Loeb *et al.,* 2017). Descriptive variables in terms of results are presented in the following chapters and include frequencies, proportions, percentages, graphs, charts and measures of central tendency (mean, median). These statistics were used to describe and summarise all the important variables in a manageable and organised way in the study (the results are presented in subsequent chapters).

3.7.1.1 *Measurement of level of product knowledge and awareness of HCFC-22 phase-out*

The ANOVA test and Tukey's honestly significant difference (HSD) test were used to evaluate product knowledge and HCFC-22 phase-out awareness. Ostertagova and Ostertag (2013) assert that the main purpose of the ANOVA test is to test whether there are any significant differences between two or more means of several independent groups. Tukey's HSD, also known as Tukey's multiple comparison test (Ramsey and Ramsey, 2008), was used in this study to test pairwise mean differences between the stakeholders' product knowledge and HCFC-22 phase-out awareness. However, before discussing how the ANOVA test used in this study was computed, it is important to highlight other studies that have formulated indices comparable to the one used in this study.

A study by Ameztegui *et al*. (2018) assessed key stakeholders' perceptions of climate change across the Canadian forest region. In that study, Ameztegui *et al*. (2018) classified the respondents' perceptions into three categories based on the degree of agreement scale and computed by summing response scores from a seven-point Likert scale and calculating pairwise post hoc comparisons. Similarly, Kapler *et al. (*2012) assessed stakeholders' level of perceptions on invasive plants using a five-point Likert scale statement and a one-way ANOVA test and comparing the means using Tukey's HSD test.

To measure the product knowledge and phase-out awareness, section B of all stakeholder questionnaires was considered. The possible responses to the relevant questions were scaled from 1 to 7, with 1 referring to a low level of knowledge/awareness and 7 representing higher levels of knowledge. Based on stakeholders' responses to the Likert-type questions, an index range from 1 to 7, representing the average level of product knowledge and awareness of the phase out for each stakeholder individual who participated in the survey, was computed. The computations were necessary as they facilitated quantitative measurement and analysis of the level of product knowledge and level of awareness of the HCFC-22 phase-out. The following equations were used to calculate the level of product knowledge and the awareness of phase-out index.

Equation 3.1: Level of product knowledge index

$$\boldsymbol{PI_i = \frac{\sum_{i=1 j=1,}^{n} X_{i,j}}{n}}$$

Equation 3.2: Level of phase-out awareness index

$$AP_i = \frac{\sum_{i=1,j=1,}^{n} X_{i,j}}{n}$$

$$1 \le PI_i, AP_i \le 7$$

Source: Researcher's own Formula

Where PI_i and AI_i are the index of product knowledge and awareness of phase-out of i^{th} individual respectively.

$X_{i,j}$ is i^{th} individual response to the j^{th} question and refers to the total number of questions asked to assess the level of product knowledge and awareness of the HCFC-22 phase-out.

An ANOVA test was then carried out to find out whether there were significant differences in the level of HCFC-22 phase-out awareness and product knowledge among the stakeholders. Tukey's HSD was also computed with the aim of identifying specific pairs of stakeholders with significant mean differences in product knowledge (section 4.3) and HCFC-22 phase-out awareness (section 4.4).

3.7.1.2 *The economic impact of HCFC-22 phase-out*

The economic impact of the HCFC-22 phase-out was assessed by comparing consumption under both constrained and unconstrained conditions. Consumption of HCFC-22 under constrained conditions refers to the consumption levels of HCFC-22 if it is phased out and unconstrained conditions assume that HCFC-22 has not been phased-out. The consumption levels were calculated for each year. The difference between unconstrained and constrained consumption was computed to ascertain the extra HCFC-22 saved by phasing out HCFC-22. The cumulative difference was then computed to find out the additional cumulative increase in consumption levels for each year from 2009 to 2017 under constrained and unconstrained conditions. Equation 3.3 and Equation 3.4 were used to calculate consumption difference and cumulative differences respectively, and the results are presented in Chapter 6, Table 6.2.

Equation 3.3: Constrained and unconstrained HCFC-22 consumption difference

$$Consumption\ difference_t = Consumption(constrained)_t - Consumption\ unconstrained\ _t$$

Equation 3.4: Cumulative differences of constrained and unconstrained HCFC-22 consumption

$$Cumulative\ consumption\ difference_t = \sum_{i=2009}^{t} Consumption\ Difference_t$$

Source: Researcher's own Formula

The total cumulative difference shows the total of HCFC-22 that would have been consumed assuming that HCFC-22 had not been phased out.

The economic impacts also involved the analysis of the impact of the HCFC-22 phase-out on servicing costs. In this analysis, it is assumed that the HCFC-22 equipment being phased out is replaced by equipment that uses R410A. As a result, its servicing costs will be affected by the price of R410A. The servicing costs of R410A are compared with the servicing costs of HCFC-22. The charge rate is assumed to be 6.3/unit/kg and the leakage rate is assumed to be 7% for HCFC-22 and 5% for R410A. Equation 3.5 was used to determine servicing requirements for HCFC-22 and R410A equipment in each year and the results are presented in Table 6.3 in Chapter 6.

Equation 3.5: Servicing requirements of HCFC-22 and R410A

$$Servicing\ requirements_t = Number\ of\ replaced\ units_t\ X\ Leakage\ rate\ X\ Charge\ rate$$

The average refilling cost for HCF-C22 and R410A is assumed to be P2.46 and P7.12 respectively (UNEP, 2018a). Equation 3.6 was then used to compute the average servicing costs of HCFC-22 and R410A for the period 2009–2017. The results were presented in Table 6.3.

Equation 3.6: Average servicing costs of HCFC-22 and R410A

$$Average\ servicing\ costs(2009-2017) = Total\ Servicing\ requirements\ X\ Average\ refilling\ cost$$

Source: Researcher's own Formula

The impact of HCFC-22 on energy costs was also assessed. Use of HCFC-22 alternatives saves about 30% energy (UNEP, 2018b). This energy saving amounts to 68 kWh/month and 816 kWh/year per unit *(ibid.)*. Equation 3.7 was used to compute energy savings per year and the results are presented in Table 6.4.

Equation 3.7: Energy saving

$$Energy\ savings_{\ t} = Number\ of\ replaced\ units\ X\ Energy\ savings\ per\ year/unit$$

The average energy cost is P1.07/kWh (UNEP, 2018a). Subsequently, the total energy savings in monetary value for the period 2009–2017 was calculated using Equation 3.8 – the results are presented in Table 6.4.

Equation 3.8: Energy cost saving

$$Energy\ savings\ in\ monetary\ value(2009-2017) = Total\ Energy\ savings(2009-2017)\ X\ Energy\ Cost$$

Source: Researcher's own Formula

3.7.1.3 *The environmental impact of HCFC-22 phase-out*

HCFC-22 has the effect of depleting the ozone layer (Kloss *et al.* 2014; Xiang *et al.*, 2014). The environmental impact of HCFC-22 was therefore analysed by determining the ODP under both constrained and unconstrained conditions. To determine the ODP under these conditions, consumption levels are used and the ODP per kilogram of HCFC-22 is assumed to be 0.055 (WMO, 2015; Li *et al.*, 2016). Subsequently, Equation 3.9 was used to calculate ODP under constrained and unconstrained conditions and the results are presented in Table 6.5 in section 6.7.2.1.

Equation 3.9: ODP under constrained and unconstrained conditions

$$ODP\ constrained = Consumption(constrained)\ X\ ODP/kg$$

$$ODP\ unconstrained = Consumption(uncostrained)\ X\ ODP/kg$$

To determine the extra ODP that Botswana saves by restricting or phasing out HCFC-22 consumption, the difference between the ODP under unconstrained conditions and the ODP under constrained conditions was computed. The ODP savings are summed up cumulatively to find out the total ODP savings per each year from 2009 to 2017. Equation 3.10 was used for this and the results are presented in Table 6.5.

Equation 3.10: Cumulative difference of ODP under constrained and unconstrained conditions

$$ODP\ difference_t = ODP(unconstrained)_t - ODP(costrained)\ _t$$

$$Cumulative\ ODP\ difference_t = \sum_{i=2009}^{t} ODP\ Difference_t$$

HCFC-22 also affects the environment through the GHGs it emits into the atmosphere (Zhao *et al.,* 2015). This causes global warming, the effects of which are measured using GWP (MWO, 2015). Like the ODP, the effect of HCFC-22 on GWP was analysed under both constrained and unconstrained conditions. A HCFC-22 GWP of 1780 per kilogram (Zhao *et al.,* 2015) was used to determine the GWP under these conditions, with the differences and cumulative differences in GWP for each year from 2009 to 2017 being computed using Equation 3.11 – the results are presented in Table 6.6.

Equation 3.11: Cumulative difference of GWP under constrained and unconstrained conditions

$$GWP\ constrained = Consumption(constrained)\ X\ GWP/kg$$

$$GWP\ unconstrained = Consumption(uncostrained)\ X\ GWP/kg$$

$$GWP\ difference_t = GWP(unconstrained)_t - GWP(constrained)\ _t$$

$$Cumulative\ GWP\ difference_t = \sum_{i=2009}^{t} GWP\ Difference_t$$

It is assumed that HCFC-22 containing units that are disposed of are replaced by units that use HCFC-22 as an alternative refrigerant. The ODP that is saved by replacing HCFC-22 units with its alternative was therefore analysed by determining the ODP that would have been obtained each year if the disposed of HCFC-22 units had been replaced by the same HCFC-22 alternative equipment. The ODP saved was computed for each year, as well as cumulatively from 2009 to 2017, using Equation 3.12 – the results are presented in Table 6.7 in section 6.7.2.3.

Equation 3.12: ODP of replaced HCFC-22 units

$$ODP\ of\ replaced\ units\ saved_{\ t} = Replaced\ units_t\ X\ ODP/kg$$

$$Cumulative\ ODP\ of\ replaced\ units\ saved_{\ t} = \sum_{i=2009}^{t} ODP\ of\ replaced\ units\ saved_{\ t}$$

In this study, it is assumed that the disposed units of HCFC-22 are replaced with R410A units. HCFC-22 and R410A have a GWP of 1 780 and 2 088 respectively (Chen, 2008; Li *et al.,* 2016) and the difference between the two is 308 GWP. The purpose then is to determine the incremental environmental cost of replacing HCFC-22 units with R410A units. Thus, the incremental GWP of using R410A units instead of HCFC-22 units and the resultant cumulative incremental GWP were computed for each year for the period 2009–2017 using Equation 3.13 – the results are presented in Table 6.8.

Equation 3.13: Incremental GWP of replacing HCFC-22 units with R410A units

$$Incremental\ GWP_{\ t} = Replaced\ units_t\ X\ Incremental\ GWP/unit$$

$$Cumulative\ Incremental\ GWP_t = \sum_{i=2009}^{t} Incremental\ GWP_t$$

Source: Researcher's own Formula

3.8 Ethical considerations

Ethics in research have to do with what is morally and professionally appropriate on the part of the researcher. This gives assurance to potential respondents that the survey will be conducted according to the highest professional standards (Stopher, 2012). The following ethical issues were considered.

3.8.1 Permission for the study

The researcher secured the requisite ethical considerations and permissions from the Ministry of Environment, Tourism and Wildlife (the approval letter is attached in the Appendix D). Further permission was sought in compliance with the UNISA ethical procedures. Informed consent is the paramount ethical consideration for the research since it empowers the respondent to contribute voluntarily in full knowledge of their rights which govern their ability to decide whether or not to participate (Fouka and Mantzorou, 2011; Stopher, 2012). Informed consent involves individuals being completely informed about a study before they willingly agree to participate (Biros, 2018). The consent process contains three elements: information, comprehension and voluntariness (Godwill, 2015). Respondents' permission was sought prior to the administration of research instruments and anonymity conditions were observed at all times. Letters were sent to the companies licensed to import ODS, as well as BURS, requesting permission to conduct the research study. These letters were subsequently signed and returned to the researcher (Appendix E).

3.8.2 Anonymity and confidentiality

The terms "confidentiality" and "anonymity" tend to be used interchangeably but are in fact distinct, albeit related concepts. Anonymity is the vehicle by which confidentiality is operationalised (Udo-Akang, 2013). Anonymity, on the other hand, is one way to apply confidentiality (Gibson *et al*., 2012; Dube *et al*., 2014). In the study, ethics were maintained by keeping the answers acquired strictly confidential. Data collected were stripped of information which allowed the identification of sources of data.

Respondents were informed about their participation in the study and were guaranteed that the data collected were genuinely for research purposes and data confidentiality was assured. Information on the identity of participants (names) was removed from the final research reports and the names of the companies that participated in the research were substituted with a code.

3.8.3 Risks

No risk of physical injury or harm was involved in the study; however, the participants were likely inconvenienced in terms of time and work focus. The interviews were conducted during working hours and this may have inconvenienced the participants. To reduce any risk, the researcher assured the respondents that information collected would not be used to exploit them. Participants were informed of their right to decline participation in the study if they decide to do so and that data collected would be kept securely and would be used for research purposes only. Participants were informed that on completion of the study, the results in the form of a copy of this thesis would be presented to the Ministry of Environment, Wildlife and Tourism Research Unit and Ethics Committee, and would also be made available in the UNISA library. The researcher was accompanied by a research assistant as she moved from company to company collecting data.

CHAPTER 4

EVALUATION OF THE STAKEHOLDERS' LEVEL OF PRODUCT KNOWLEDGE AND AWARENESS OF HCFC-22 PHASE OUT

4.1 Introduction

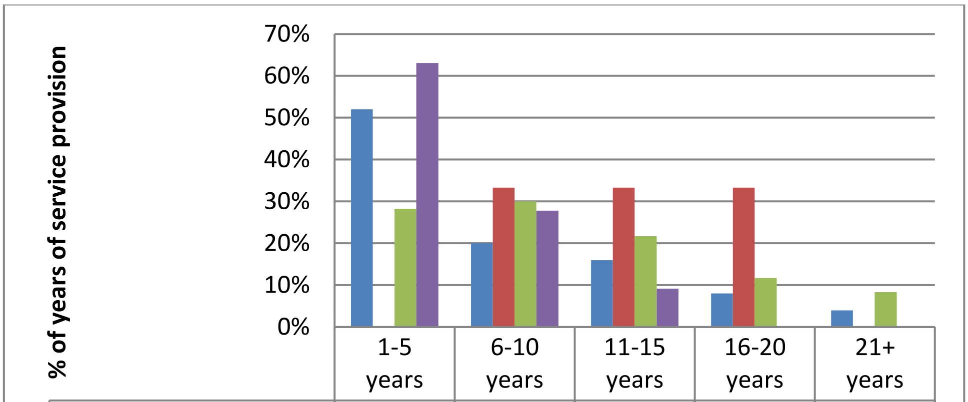
The success of Botswana's HCFC-22 phase-out strategy depends on the participation of key stakeholders in the implementation process. In this study, the key stakeholders in the implementation of the HCFC-22 phase-out strategies are the DMS (NOU), customs officers, companies that import ODS and consumers/customers that buy the refrigerants. Thus, the assessment of stakeholders' knowledge and awareness on HCFC-22 is very important; according to decision-making theory, people generally form attitudes about technologies when they have attained relevant information (Latifah *et al*., 2011). For the HCFC-22 phase-out strategies to be effective, these stakeholders are expected to have a deeper knowledge of the phase-out strategies themselves. As a result, the indicators of a successful HCFC-22 phase-out strategy are the level of product knowledge key stakeholders possess and their level of awareness of the phase-out strategy itself. This chapter also reflects on the Botswana's HCFC-22 phase-out management system. Data analysed were taken from the reviewed documents, interviews and questionnaires.

4.2 Demographic data of respondents

The demographic characteristics of the respondents investigated included stakeholders' years of service provision, level of education and managerial positions. These variables have implications for the HCFC-22 phase-out process and are used as background information for subsequent sections.

4.2.1 Respondents' years of service provision

Years of service provision is the total number of years stakeholders have spent dealing with HCFC-22 and other ODSs, and is a continuous variable. The more experienced the stakeholder is, the better informed he/she is assumed to be about the HCFC-22 phase-out awareness and the more he/she is likely to play a major role in implementation of the country's HPMP (UNEP, 2017a).



	1-5 years	6-10 years	11-15 years	16-20 years	21+ years
DMS	52%	20%	16%	8%	4%
Importers		33,30%	33,30%	33,30%	
Customs officers	28,30%	30%	21,70%	11,70%	8,30%
Consumers (end users)	63,10%	27,80%	9,20%		

Figure 4.1: Respondents' years of service provision in the HCFC-22 industry

The results displayed in Figure 4.1 indicate that the majority of HCFC-22 consumers (63%) and the DMS (52%) have been dealing with HCFC-22 and other ODSs for at most five years, while all HCFC-22 importers' length of service provision is more than six years. Customs officers (8%) and DMS (4%) have more than 21 years of dealing with ODS. It is therefore expected that they will have more knowledge of the HCFC-22 phase-out, since the phase-out of HCFC-22 started in 2009.

4.2.2 Respondents' level of education

Level of education is a continuous variable measured in terms of stakeholders' years of formal schooling. In relation to level of education, respondents were observed according to the highest educational level completed. Overall, seven educational levels, as reflected in the questionnaire, were defined: respondents who had completed secondary school education (O level and A level), respondents who had completed pre-university education (certificate or diploma) and respondents who had completed university education (graduate degree, master's degree and doctoral degree). The level of education achieved by a stakeholder is used as a proxy for increasing HCFC-22 phase-out awareness input. Education enables a person to read, write and understand diverse information including knowledge of HCFC-22 phase out. From the analysis of the respondents' educational level, it may be seen that only a small number had just a secondary school education and these were consumers (13%). In contrast, very few respondents had master's and doctoral degrees. Most of the respondents had pre-university education (certificate or diploma) (63%) and university education (graduate degree) (24%)

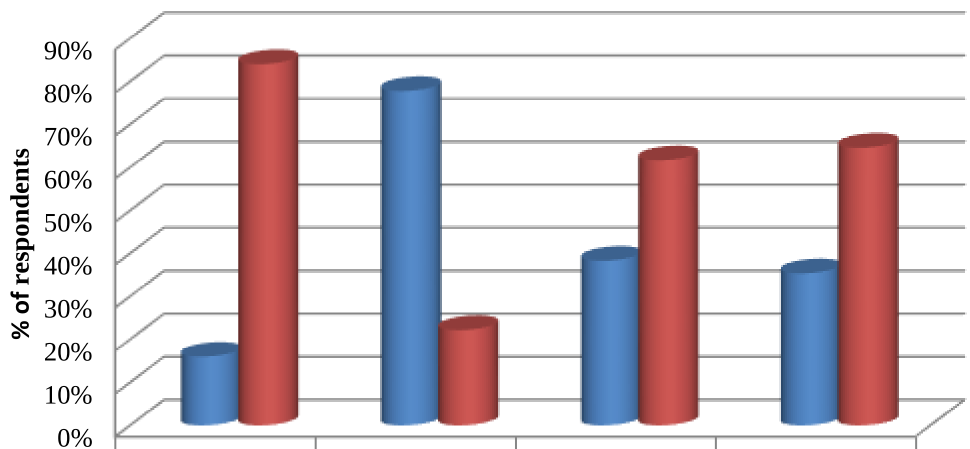
(Table 4.1). Stakeholders with higher levels of education were expected to know and understand the HCFC-22 phase-out process.

Table 4.1: Respondents' highest level of education (percentage)

Level of Education	DMS %	Importers %	Customs officers %	Consumers (end users) %	Total %
O Level	0	0	0	12.30	13
A Level	0	0	0	9.20	
Certificate	16	11.10	35.00	16.90	63
Diploma	40	55.60	43.30	30.80	
Graduate degree	32	33.30	20.00	18.50	
Master's degree	8	0	1.70	6.20	24
Doctoral degree	4	0	0	6.20	

4.3 Respondents' managerial positions

Respondents were also analysed according to their positions of responsibility in their organisations or enterprises. Consequently, two levels were recognised: respondents in management and those in non-management. The distribution of respondents' management positions is presented in Figure 4.2.



	DMS	Importers	Custom officers	Consumers (end users)
Management	16%	77,80%	38,30%	35,40%
Non Management	84%	22,20%	61,70%	64,60%

Figure 4.2: Respondents' managerial positions in HCFC-22 service provision

On average, most of the respondents in the survey were considered part of non-management in their respective organisations: DMS (84%), consumers (64.6%) and customs officers (61.7%). Nevertheless, some respondents in the non-management category were able to give detailed information on the HCFC-22 phase-out. By contrast, most respondents in management were to be found among the importers of HCFC-22 (77.8%). Respondents in management were able to provide detailed information on the HCFC-22 phase-out.

4.4 Evaluation of stakeholders' level of HCFC-22 knowledge

It is significant to assess stakeholders' HCFC-22 knowledge or phase-out awareness because, according to decision-making theory (Latifah *et al.* 2011), people only form attitudes about technologies after they have attained information. Regarding product knowledge, stakeholders were asked about their knowledge of the use of HCFC-22. Accordingly, differences in stakeholders' mean levels of HCFC-22 knowledge and individual stakeholder levels of HCFC-22 knowledge were computed. Table 4.2 shows the computed mean and the associated confidence interval for the mean on stakeholders' overall level of HCFC-22 knowledge.

Table 4.2: Stakeholders' overall mean level of HCFC-22 knowledge

Mean	Standard deviation	Confidence interval 95%	Interpretation
4.15	0.56	[4.06;4.24]	Moderate

*0–2.99, low; 3–5.99, moderate; 6–7, high

The computed mean level of 4.15 showed a moderate level of HCFC-22 knowledge (4.15 out of 7). The 95% confidence interval for the mean is between 4.06 and 4.24. Considering that scale maximum level is 7, the overall average level of product knowledge is relatively moderate. Stakeholders possess a moderate level of HCFC-22 knowledge, probably because some among them are not direct users of the product and may lack awareness. For the success of the phase-out management plan, it is essential for stakeholders to have HCFC-22 knowledge.

4.4.1 Comparing the level of the HCFC-22 knowledge of individual stakeholders

The researcher examined the differences in the levels of HCFC-22 knowledge among the four key stakeholders in the implementation of the HCFC-22 phase-out strategy. The differences in the levels were examined using box plots (Figure 4.3). The dark line in the box plots signifies the median value. The bottom and the top of the boxes signify the lower and upper quartiles respectively, and the bars extend to 1.5 times the height of the box (Hinlo *et al.,* 2017). The circle outside the bar of the DMS is marked as an outlier, having more than three times the height of the box plot.

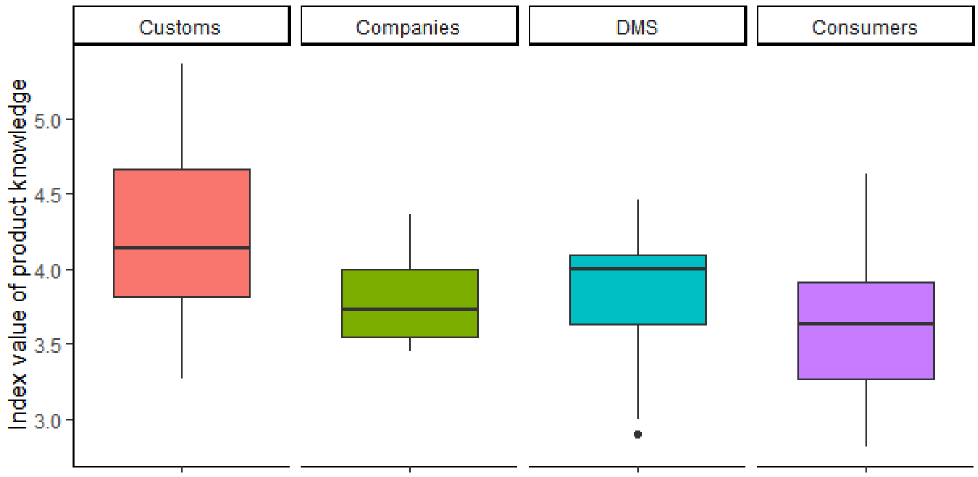


Figure 4.3: Box plot comparing index value of stakeholders' HCFC-22 knowledge

The medians for customs officers and the DMS are higher at 4.14 and 4.0 respectively than the medians for companies (3.73) and consumers (3.64). This indicates that customs officers and the DMS have higher levels of HCFC-22 knowledge than the companies and the consumers. However, the customs officers have the most knowledge of all the other stakeholders. This is probably because customs officers are responsible for checking and identifying all the ODSs that pass through the entry points to verify compliance with regulations; hence, they should necessarily have extensive knowledge of HCFC-22 and its phase-out process. The DMS comes a close second, which is hardly surprising since it is the body charged with coordinating the country's efforts to protect the ozone layer. It does this by facilitating ODS phase out and offering advice and support to the industry and the services sector on the different phase-out options for ODS, as well as presenting awareness programmes directed at end users.

Consumers have the lowest knowledge of HCFC-22 refrigerant. Quite clearly, there is a disconnect between the technical stakeholders of the HCFC-22 phase-out process (customs and the DMS), who should dispense HCFC-22 knowledge, and the non-technical stakeholders (end users are by far the most important recipient stakeholder). One of the key premises that this researcher holds true is that there must be conscientisation, capacitation, cooperation and compliance of all key stakeholders in the entire HCFC-22 phase-out plan in order for any success to be achieved. The identified knowledge gaps do not bode well for the successful implementation of the HCFC-22 phase-out plan. The UNEP (2019b) asserts that awareness influences market and consumer choice, and a good consumer communication strategy is critical to increasing the market penetration of more efficient products.

The current position is consistent with the finding by the UNDP and the GEF (2017) that key stakeholders in developing countries generally possess limited awareness of the issues or actions required on the higher or technical level to address HCFC phase-out. This, they add, is in turn a function of low levels of phase-out awareness programmes by companies that import ODSs. This is, without seeking to pre-empt recommendations for the way forward, an area in which technical stakeholders should improve the quality and quantity of their awareness-raising efforts.

The mean levels and standard deviations of product knowledge of individual stakeholders were computed and the results are presented in Table 4.3.

Table 4.3: Individual stakeholders' mean levels of HCFC-22 knowledge

Stakeholder	Mean	Standard deviation	Confidence interval (95%)		Interpretation
			Lower limit	Upper limit	
Customs	4.24	0.563	4.10	4.38	Moderate
Companies	3.82	0.298	3.62	4.01	Moderate
DMS	3.83	0.451	3.66	4.01	Moderate
Consumers	3.61	0.418	3.51	3.72	Moderate

*0–2.99, low; 3–5.99, moderate; 6–7, high

The results (Table 4.3) show that all stakeholders have moderate level of HCFC-22 knowledge, with customs officers (4.24) having the highest mean level of HCFC-22 knowledge followed by the DMS (3.83), companies (3.82) and consumers (3.61), since customs officers are responsible for checking and monitoring all ODS at entry points. Companies and the DMS have almost the same levels of HCFC-22 knowledge; this is commendable in light of their roles. As the end users, consumers and customers are expected to have a deeper understanding of the product because they are the ones who directly use HCFC-22 and they are also directly affected by its phase-out. Although the results in Table 4.3 show moderate HCFC-22 knowledge, consumers possess the least mean knowledge (3.61). Nevertheless, with adequate training and awareness programmes, one would expect all stakeholders to possess higher levels of HCFC-22 knowledge. In the event, only customs and the DMS possessed high HCFC-22 knowledge, with final consumers being at the lower end of the knowledge scale. This suggests that current awareness-raising efforts and initiatives are inadequate. Correspondingly, this lack of consumer awareness is identified by the UNEP (2019b) as one of the main barriers to the successful phase-out of HCFC-22s. In particular, the UNEP (2019b) points out that consumers lack information on the most energy efficient and environmentally friendly alternatives to HCFC-22 in line with the Kigali Amendment. Ideally, information dissemination should take place in continuously and also be present at the point of purchase when customers are at their most receptive. In addition, it should be multi-tiered in order to reach retailers and installers (*ibid.).*

The stakeholder differences in mean level of product knowledge were further analysed using ANOVA and Tukey's HSD tests of mean differences. The differences in the mean levels of HCFC-22 product knowledge among the stakeholders were significant at a 5% level of significance ($F = 12.52$; $Pr(> F) = 3.49e^{-10}$). The ANOVA test, as shown in Table 4.4, indicated that there were significant differences among the stakeholders on level of HCFC-22 product knowledge. The analysis undertaken so far indicated that stakeholders had different levels of knowledge with regard to HCFC-22, with customs officers having higher levels of knowledge compared to other stakeholders. These differences in levels of HCFC-22 knowledge may have a negative effect on the success of the HCFC-22 phase-out management plan. The significance of the differences in HCFC-22 knowledge among stakeholders was computed using an ANOVA test.

Table 4.4: ANOVA test of stakeholders' mean difference in product knowledge

	Difference	**Sum of squares**	**Mean of squares**	**F value**	**Pr (>F)**
Stakeholders	3	12.52	4.175	18.23	$3.49e^{-10}$
Residuals	155	35.49	0.229		

A multiple pairwise test of mean difference was carried out to identify specific stakeholders with significant mean differences in level of knowledge, and the results are presented in Table 4.5. Tukey's HSD was used to perform the test, as explained in section 3.6.1.1.

At the 5% level of significance, Table 4.5 shows that there are significant differences in mean levels of HCFC-22 knowledge between DMS and customs, as well as between consumers and customs. As discussed in section 4.3.3, customs officers have high levels of product knowledge as compared to companies, the DMS and consumers. This pairwise test shows that the customs officers' higher level of HCFC-22 knowledge is significantly different from the mean levels of

HCFC-22 knowledge of other key stakeholders. There are, however, no significant differences in mean levels of HCFC-22 knowledge between DMS and companies, between consumers and companies and between consumers and DMS. Although consumers, the DMS and companies have different mean levels of HCFC-22 knowledge, the difference is not significant.

Table 4.5: Multiple pairwise test of mean difference of level of product knowledge

Stakeholder	Mean difference	Lower limit	Upper limit	p adj	Interpretation
Companies – customs	-0.4242	-0.8685	0.02	0.067	No significant difference
DMS – customs	-0.4097	-0.7055	-0.1139	0.0024	Significant difference
Consumers – customs	-0.6284	-0.8509	-0.4059	0	Significant difference
DMS – companies	0.0145	-0.4686	0.4977	0.9998	No significant difference
Consumers – companies	-0.2042	-0.6462	0.2378	0.6279	No significant difference
Consumers – DMS	-0.2187	-0.5112	0.0737	0.2148	No significant difference

A similar study in Mauritius by Dreepaul (2017) produced contrasting results to the current one, with stakeholders in the market conversant with the issues of HCFC and CFCs refrigerants and the desirability of alternative natural refrigerants, as well as with ozone depletion-related problems. Repair and maintenance companies were more knowledgeable about HCFC than self-employed private mechanics, while technicians, often trained in the field itself, were found wanting in the procedures and precautions for the retrofitting of new refrigerants. The reasons for the disparity with the current study could be the inadequate training and awareness programmes offered to RAC technicians in the informal sector.

4.5 Evaluation of the level of HCFC-22 phase-out awareness

Besides product knowledge, stakeholders were also expected to have a deeper level of the HCFC-22 phase-out awareness, as described by the Botswana HPMP. In the Botswana HPMP, awareness of key stakeholders on HCFC-22 phase-out was one of the key deliverables (UNIDO, 2015). The idea was that deeper awareness of the HCFC-22 phase-out plan among stakeholders would help Botswana reduce consumption of HCFC-22. The level of awareness of the key stakeholders (participants) was measured in a similar manner to the level of HCFC-22 knowledge (section 4.3), using an index computed based on survey questions related to the awareness of HCFC-22 phase-out. Table 4.6 shows the overall mean level of awareness of HCFC-22 phase-out.

Table 4.6: Estimating the overall mean level of awareness of HCFC-22 phase-out

Mean	Standard deviation	Confidence interval 95%	Interpretation
3.25	0.57	[3.17; 3.34]	Moderate

*0–2.99, low; 3–5.99, moderate; 6–7, high

The computed mean level of 3.25 showed a moderate level of HCFC-22 awareness (3.25 out of 7), while the 95% confidence interval for the mean is between 3.17 and 3.34. Considering that scale maximum level is 7, the overall average level of HCFC-22 phase-out awareness is averagely moderate. This is essential for the success of the HCFC-22 phase-out. In fact, the UNEP (2019b) cites lack of consumer awareness as one of the main barriers to the successful phase out of HCFC-22; the corollary to this is that consumer awareness is an essential ingredient for successful HCFC-22 phase-out. Considering this authoritative assessment by the UNEP of the importance of consumer awareness, moderate awareness by this critical stakeholder constituency seems inadequate and, quite clearly, lots more work needs to be done to improve the levels of awareness. In fact, this researcher suggests that awareness of HCFC-22 phase-out must be high among all stakeholders without exception in order for the HPMP to register success. The particular case of Mauritius amply demonstrates the importance of consumer awareness, with alternative HFC refrigerants such as R134A, R404A, R407C and R410A predominating in that country's RAC sector, and HCFC-22 use steadily on the decline in limited applications like split AC units and large industrial and commercial applications (Deepaul, 2017). In reviewing the progress of Bahrain, India, Iraq, Kuwait, Oman, Pakistan, Qatar, Saudi Arabia, the Islamic Republic of Iran and the United Arab Emirates, the UNEP (2019c) notes that stakeholders' participation in those countries has proven effective in providing them with a sense of ownership of HCFC-22 phase-out projects and in raising awareness among end users and industry players.

Comparisons of the level of awareness of the individual stakeholders in HCFC-22 phase-out, as shown in Figure 4.4, reveals that consumers have the highest median (3.54) level of awareness of HCFC-22 compared to the other stakeholders. It is ideal for consumers to have the highest awareness of HCFC-22 phase-out because they are the direct users of the product and are also directly affected by the phase-out.

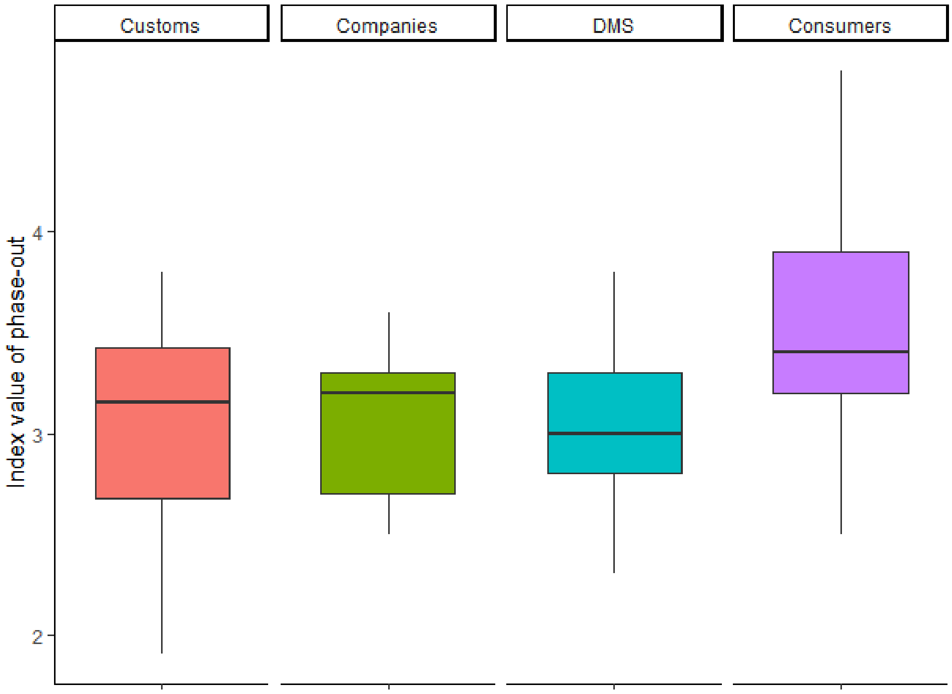


Figure 4.4: Analysis of stakeholders' HCFC-22 phase-out awareness level

Consumers are followed by companies (3.11) with a slightly higher median for the HCFC-22 phase-out awareness than customs (3.06). Customs and companies have an almost similar median of awareness (3.06 and 3.11 respectively) and the DMS has the lowest median (3.03) of HCFC-22 phase-out awareness. The fact that consumers and companies display higher levels of awareness of the HCFC-22 phase-out than other stakeholders may be reasonable considering that the phase-out directly affects them. The DMS has the lowest median and third quartile despite the fact that they are key implementers of the HCFC-22 phase-out.

When asked if Botswana is mandated to phase-out HCFC-22, 30% of all the stakeholders strongly agreed, 6% somewhat agreed, 44% agreed and 14% were neutral. This means most stakeholders (80%) are aware of the HCFC-22 phase-out. However, the stakeholders' phase-out awareness differed when asked about the specific elements of the phase-out: about 62% of customs officers, 57% of DMS, 31% of consumers and 11% of companies strongly disagreed that HCFC-22 quota allocations, HCFC-22 licensing and legislative restrictions were in place. About 75% of all stakeholders were not aware of the existence of the Botswana HPMP.

The UNEP (2010d) posited that raising awareness of the HCFC-22 phase-out with company owners permits them to make informed investment decisions and contributes to accelerated phase out. However, it is essential that all parties possess higher levels of HCFC-22 phase-out awareness in order for it to succeed. With adequate training and awareness activities, it would be expected that such differences between stakeholders are minimal and insignificant. The differences in stakeholders' level of HCFC-22 phase-out awareness may be a result of the different training and awareness programmes received by stakeholders, which results in some stakeholders being more informed than others. Study results indicate that 68% of customs officers received training and ODS awareness from the NOU. About 65% of consumers revealed that they had discussed HCFC-22 with their suppliers (companies). The UNIDO (2015) revealed that BRACA is responsible for sharing information among stakeholders on ODS phase out and coordinating the country's training programmes in conjunction with the NOO. There have also been training challenges relating to specific stakeholder groups. For example, the UNEP (2019d) laments that in Botswana it has been difficult to gather informal RAC technicians. The growth of BRACA has also been hampered by the fact that most members come from the private companies who have ever busy schedules, which adversely affects training and phase-out awareness initiatives and programmes. HCFC-22 phase-out awareness activities which target all stakeholders would help increase their support for HCFC-22 phase-out. Hence, the mean level of the HCFC-22 phase-out awareness of each individual stakeholder was computed and the results are presented in Table 4.7:

Table 4.7: Individual stakeholders' mean level of HCFC-22 phase-out awareness

Stakeholder	Mean	Standard deviation	Confidence interval (95%)		Interpretation
			Lower limit	Upper limit	
Customs	3.06	0.473	2.95	3.18	Moderate
Companies	3.11	0.414	2.84	3.38	Moderate
DMS	3.03	0.416	2.86	3.19	Moderate
Consumers	3.54	0.613	3.39	3.69	Moderate

*0–2.99, low; 3–5.99, moderate; 6–7, high

Table 4.7 also shows that the overall mean level of HCFC-22 phase-out awareness was moderate among all stakeholders. The highest value among the stakeholders was obtained for the consumers followed by companies, customs and DMS. Consumers and companies are directly affected by the HCFC-22 phase-out and as such it may not be surprising that they have deeper knowledge of the HCFC-22 phase-out plan as compared to the other stakeholders. Since they are the targeted stakeholders in as far as the reduction of HCFC-22 consumption levels is concerned, higher awareness levels of the HCFC-22 phase-out for this group may help in achieving a successful HCFC-22 phase-out. In addition, suppliers of HCFC-22 are required to discuss the HCFC-22 phase-out with end consumers as a requirement of the ODS regulation (GoB, 2014b). Survey results indicate that some companies (45%) discuss phase out with their customers. On the other hand, a small majority of end-user consumers (65%) indicated that they have discussed the phase-out of HCFC-22 with their suppliers. This also contributes to consumers and companies having higher HCFC-22 medians of awareness. However, since DMS and customs officers are responsible for the implementation and enforcement of the HCFC-22 phase-out management plan, they are expected to have higher HCFC-22 phase-out awareness levels. In other words, their awareness of the HCFC-22 phase-out plan should not be different from other stakeholders, considering the critical role that they play in the implementation of the Botswana HPMP. When participants from the DMS were asked about the extent to which they complied with and enforced the ODS regulations as contained in the Act and Botswana HPMP, most DMS respondents (76.5%) believed that their level of compliance with implementation and enforcement of specific key provisions of Act and the Botswana HPMP was moderate, with only 23.5% believing that their level of compliance was low. This also explains why the DMS has the lowest mean level (3.03) of HCFC-22 phase-out awareness.

The differences in the mean levels of HCFC-22 phase-out awareness among the stakeholders were significant at the 5% level of significance ($F = 10.64$, **Pr (> F**) = $2.12e^{-6}$). The ANOVA test, as shown in Table 4.8, indicates that there were significant differences among the stakeholders on the level of HCFC-22 phase-out awareness.

Table 4.8: Stakeholders' mean levels of HCFC-22 phase-out awareness

	Difference	Sum of squares	Mean of squares	F value	Pr (> F)
Stakeholders	3	8.81	2.9356	10.64	$2.12e^{-6}$
Residuals	155	42.77	0.2759		

These results imply that the knowledge possessed by the key stakeholders concerning the HCFC-22 phase-out plan was significantly different and could contribute to differences in the effective implementation of HCFC-22 phase-out.

Table 4.9 shows a Tukey's HSD multiple pairwise test result of the pairs of stakeholders, which revealed significant differences in level of awareness of the HCFC-22 phase-out.

Table 4.9: Multiple pairwise test of mean differences in level of HCFC-22 phase-out

Stakeholder	Mean difference	Lower limit	Upper limit	p adj	Interpretation
Companies–Customs	0.0461	-0.4415	0.5338	0.9948	No significant difference
DMS–Customs	-0.037	-0.3617	0.2878	0.991	No significant difference
Consumers–Customs	0.4719	0.2277	0.7162	0	Significant difference
DMS–Companies	-0.0831	-0.6134	0.4472	0.9771	No significant difference
Consumers–Companies	0.4258	-0.0594	0.911	0.1074	No significant difference
Consumers–DMS	0.5089	0.1879	0.83	0.0036	Significant difference

The results of Tukey's HSD multiple pairwise test revealed that there were significant differences in awareness of the HCFC-22 phase-out between consumers and customs officers. However, no other significant differences were found between pairs of other stakeholders. This means that consumers had significantly higher levels of awareness of the HCFC-22 phase out than customs officers. This should be a cause for concern because customs officers are responsible for processing of the importation of HCFC-22 at the country's entry points/border posts. Hence, they should have more extensive knowledge of the phase out so that they can effectively implement the HCFC-22 phase-out import control regulations. There are lessons to be gleaned elsewhere on the critical role of training in the implementation of HCFC-22 phase-out plans. One is the Government of Cuba which, reports the UNEP (2019e), through the training of technicians, technical classrooms for the RAC sector, and public awareness raising programmes on the protection of the ozone layer, has made progress in implementing the phase out of HCFCs and has achieved the first reduction goal (10% of the baseline). Similarly, Trinidad and Tobago, having effectively achieved stage I of the country's HPMP, is currently developing stage II of its HPMP. The progress made is largely attributed to its participation in global and regional network meetings, training sessions and high-level meetings for the promotion of MP activities in the country (*ibid.*).

4.6 An evaluation of Botswana's HCFC-22 phase-out management system

In its assessment of Botswana's HCFC-22 Phase-out Management Plan, UNEP (2015a) and UNIDO (2015) observe that the country has scored success in implementing the Terminal Phase-out of the chlorofluorocarbons, pursuant to the objectives of the Terminal Phase-out Management Plan (TPMP). This was through and by successful implementation of projects such as the refrigeration management plan, Methyl Bromide demonstration project and the CFC TPMP. They attribute this success to the implementation in a timely manner of the TPMP through which total phase-out was achieved by December 2010 (UNIDO, 2015). From the implementation of the TPMP emerged lessons and learnings which proved germane to the HCFC Phase-out Management Plan.

The HCFC consumption in Botswana has been decreasing since 2013. As reported in Section 6.4; UNEP, (2018f), this was due to the implementation of the licensing and quota system for HCFC import control; the activities in the refrigeration servicing sector; and awareness-raising activities. This has reduced the demand for HCFC-22 through promotion of natural refrigerants and other viable HCFC-22-alternative technologies. The current (2016 to 2020) HCFC-22 phase-out management system of Botswana is couched as its HPMP (literature review section 2.12.1.2). This is in keeping with the provisions of the MP, by which, the phase-out of HCFC-22 in Article 5 countries was planned to have been largely completed by 2030, the aim being to reduce HCFC-22 consumption by 97.5% on a base level from 2009-2010 (Fortems-Cheiney *et al*., 2013; Wang *et al*., 2016; literature review section 2.9).

4.6.1 Botswana HPMP's organisational structure and function

Operationally, the HPMP combines regulatory, capacity building, investment and awareness campaigns to enable Botswana to meet its HCFC-22 phase-out obligations. These include dissemination of ODS regulations, training programmes for Customs Officers and other relevant law enforcers, strengthening the customs training curricula, training for refrigeration service technicians, promotion of the adoption of the alternatives, awareness campaigns, retrofit and recovery activities, assisting end-users and the provision of tool kits (UNEP, 2015a; UNEP, 2018f). The main components of the HCFC-22 phase-out management plan are, externally, the funding / resourcing structure provided for by the MP to enable signatories to meet their MP obligations, as well as the general provisions of the same for signatories. Internally at national level, the system comprises national implementing and coordinating partners, the national legislative or regulatory framework, and control systems for the supply and flow of ODS and ODS-dependent equipment. The MP provides regulatory and non-regulatory guidelines which form the planning and implementing framework for Article 5 signatories to the protocol (*ibid.)*.

As reported in literature review (section 2.12.1.3), a number of bodies and organisations were established in Botswana to implement the licensing and quota system. The ministry under whose ambit ozone-related activities fall is the Ministry of Environment, Wildlife and Tourism. Within it is the DMS, headed by a Director, who oversees the function and the implementation of the HPMP (UNEP, 2015a, 2018f; UNIDO, 2015). Under the DMS is the NOU, which coordinates and monitors the implementation of the daily activities of the HPMP and is expected to periodically review performance of individual projects, and prepare quarterly progress reports for the same. Additionally the Director DMS, as the head of the NOO, issue instructions in pursuit of the implementation of the principal ozone-protecting Act and issue notices to control the use of HCFCs, thus ensuring Botswana complies with the set obligations under the MP (*ibid.*).

Interview results from the NOO revealed that, it is crucial to note the importance of the monitoring and reporting activities of the NOU as they carry financial implications. For starters, it is the NOU's responsibility to see to Botswana's meeting of the country's annual consumption limits of the ozone-depleting substances specified by the MP. Botswana is ineligible to apply for or receive further funding from the MLF with regards to any consumption of the ODS above the agreed levels. This is because the country agreed to meet the HCFC-22 annual target limit consumption and funding agreement as per MP schedule. Thus, timely and accurate reporting on the progress of the country's HPMP is one of the NOU's key responsibilities (*ibid.)*.

Specifically, a written description of the activities to be undertaken until and including the year of the planned submission of the next tranche request, highlighting the interdependence of the activities, and taking into account experiences made and progress achieved in the implementation of earlier tranches; the data in the plan will be provided by calendar year. The description should also include a reference to the overall plan and progress achieved, as well as any possible changes to the overall plan that are foreseen.(UNEP, 2020).

4.6.2 The Botswana's HPMP legislative and policy provisions

The MP provides binding regulatory guidelines to signatories to facilitate the execution of their obligations and compliance with the HCFC-22 phase-out schedule. As discussed in literature review section 2.10.1 and Gloel *et al*. (2017), the ODS regulations have been instituted by most developing countries to guide MP implementation and its associated ODS phase-out provisions and schedules. The regulations revolve around the control of the manufacture, import, export and consumption of restricted substances, including HCFC-22. Specifically, handling of ODS, gas recovery at the stages of servicing and decommissioning, activities related to the collection, training and certifying of technicians, enforcing regulations, bans on some products, control of leakages and reporting of imports/exports.

In Botswana, the principal regulations governing all activities aimed at reducing consumption of ODS and by extension, its climatic effects were gazetted under the National Meteorological Services Act, 2014. Under the regulations, measures were put in place to control the consumption of HCFCs by restricting the importation and exportation of ODS, and promoting the retrofitting of HCFC-based equipment (UNEP, 2015a; UNIDO, 2015). To that end, the regulations empower the Director of the DMS to "*prohibit and control the use, movement and trading in ODSs controlled under the Montreal Protocol on substances that deplete the ozone layer*." and to "*ensure Botswana complies with its obligations under the Montreal Protocol*" (*ibid.)*.

The same ODS regulations under the National Meteorological Services Act, 2014 made provision for a HCFC-22 licensing and quota system. This system has been established and operationalised (UNEP, 2015a and UNIDO, 2015). The regulations allow both licensing of importers as well as imposition of quotas on HCFC-22 and HCFC-22-based equipment to comply with the ODS phase-out obligations. The system further puts in place a mechanism to verify facilities handling HCFCs to ensure that they have adequate human capacity and equipment to manage HCFCs in an environmentally sound manner. These facilities are subject to regular checks by the NOO to verify that they comply with the set standards (UNEP, 2015a). The 2015 HCFC-22 quota for importation was put at 180 metric tons, in line with the 10% HCFC 2015 reduction target (*ibid.*).

In order to further strengthen compliance and enforcement of the regulations, interview results from the NOO revealed that there is need to further raise awareness on the ODS Regulations and put in place various measures to build capacity of relevant regulatory institutions involved in the implementation of HCFC-22 quota system. In line with that, the training curriculum for customs officers has been updated to include new obligations under the MP. Botswana also established an institutional framework and communication channels to involve stakeholders; the national ozone committee, the national licensing committee and the national monitoring committee to manage the licensing and quota system for HCFC-22 imports and to promote public awareness on the protection of the ozone layer and related climate benefits.

4.6.3 Stakeholder's engagement in the HCFC-22 phase-out management plan

As reported in the literature review section 2.12.1.3 on implementation partners for the HCFC-22 phase-out management plan, the key stakeholders in Botswana's HPMP are the triad of Government, the public and industry. According to the NOO interview results, the key players in the government are the ministry/department of commerce, trade, energy, mining, education (the university of Botswana and vocational training institutes responsible for technicians training) and information (the media both public and private). Other identified players include the BURS, attorney general's chambers, Botswana chamber of commerce industry and manpower and BRACA. The refrigeration and air-conditioning sector and users of the HCFCs include repair workshops, ODS importers, technicians, main users including owners of public/private buildings/hotels/hospitals and supermarket chains as well as importers of products containing HFCs/HCFCs (furniture /appliance shops).

The DMS houses the NOO which specifically coordinate the licensing committee and monitoring committee as envisaged under the National Meteorological Services Act. The national ozone committee continues to provide guidance to the NOO in achieving the targets as stipulated under the HPMP. The NOO reported that the NOU engaged the identified stakeholders at a number of fora. Importantly, the NOU held various meetings with the interministerial committee on treaties, ponventions and protocols, which comprises members from all ministries of the government. UNEP (2019d) also reports that some of these meetings targeted educating different stakeholders on the adoption of the ODS legislation. Amongst them is the Ministry of Foreign Affairs on 5th June 2018 and the inter-ministerial committee on conventions on the 30th May 2018. At the same meetings, the committee was updated on the different activities under the MP Botswana's national and international achievements and the African network meeting that the country hosted in May 2018. These activities were followed up in January and February 2019, with meetings with RAC sector stakeho from government and the private sector (hotels, supermarkets, refrigeration companies, BRACA) in the North and South Eastern parts of the country.

However there remains a gap in stakeholder engagement when it comes to the private sector. Interviews with HCFC-22 importers (67%) and NOO suggested that there were coordination gaps and challenges in relation to meeting private company operators, due to scheduling disharmony between their work plans and the engagement meetings.

4.6.4 HPMP institutional capacity building issues

According to NOO interview results, a multi-pronged approach is in place in Botswana for institutional capacity building. This involves, among other things, coordinating and organising the training of customs officers in the detection of ODS and refrigeration technicians, implementation and enforcement of ODS legislation and regulation. The NOU also timely report ODS consumption data to the ozone secretariat and country programme to the MLF Secretariat and conduct nationwide awareness activities on ODS-related dangers; participation in international meetings organised by UNEP, and implementation of decisions approved by various meetings of the parties (*ibid.*).

A few progress highlights in relation to the above are worth noting. Consultations with stakeholders on allocation of imports have thus far been consistently done, scheduled meetings of the licencing committee convened, and joint border dialogues conducted between Botswana and its two neighbours, Zimbabwe and Zambia in 2018 and 2019 (UNEP, 2019d). Additionally, it was reported that different stakeholders were educated on the adoption of the ODS legislation, including the Ministry of Foreign Affairs on 5th June 2018, the inter-ministerial Committee on Conventions on 30th May 2018 (*ibid.*). Of concern, however was the inertia from the industry when it came to application for permits as they only applied for those after being returned from the ports of entry.

As far as data reporting is concerned, that was successfully done in 2016 and 2018, but this continued to be hampered by late submission of data by importers and lack of proper coding and classification for ODS (UNEP, 2019d). In the period 2016-2018, awareness-raising activities were carried out every year including on ozone day, and at various environmental day commemorations in 2016, 2017 and 2018. These were the world tourism day, world wetlands day and world environment day. These targeted the general public as well as RAC sector players. The country has similarly been an active participant in at regional and international meetings, and continues to implement decisions approved at various meetings of the Parties, including significantly the Kigali Amendment.

All the above initiatives, activities and campaigns obviously can only be feasible with consistent, adequate funding. The agreement between Botswana and the Executive Committee of the MLF is that the country would be eligible to apply for and receive funding if it met the ODS consumption reduction targets spelt out in the MP (UNEP, 2018f). Specifically, stage I of the Botswana HPMP for the period 2015 to 2020 aimed to reduce HCFC consumption by 35% of the baseline of 11.0 tons, and for that, funding in the amount of US$616 000 was approved in principle. In the event, the 2018 verification report confirmed the effectiveness of Botswana's licensing and quota system for HCFC-22 imports and exports since 2015, and that the total consumption of HCFCs for 2017 was 8.58 ODP tonnes, which was 22% below the target 11.0 tonnes.

Based on that record, the Fund Secretariat recommended in 2018 that the Executive Committee took special note of the positive strides made in implementing the first tranche of stage I of the HPMP for Botswana (UNEP, 2018f; 2020). In the light of the same, the country be given blanket approval of funding for the second tranche of stage I of the HPMP for Botswana, and the corresponding 2018-2020 tranche implementation plan. Thus, as of September 2018, of the US$275 000 approved for the first tranche, US$185 000 (representing 67% of approved funding) had been disbursed, with the balance of US$90 000 to be disbursed in 2019 (*ibid.)*.

4.6.5 HCFC-22 phase-out management operational action plan

The NOO, in the 2019 National Projects Scope Report, identifies the following key initiatives in the country's operational plan: training of customs and other law enforcement officers, and strengthening of BRACA and the customs training schools. The strengthening of the three regional retrofitting centres through provision of technical assistance, equipment and incentive programme for access of tool kits, spare parts, and alternative fluid is also a priority (UNEP, 2018f). Other activities include training of refrigeration technicians in good refrigeration practices, promotion of low GWP alternatives, safety in the use and handling of hydrocarbons and coordination.

The NOO reported that as at 2019, training has almost been completed, with more than 75% (615) of customs officers at all ports of entries having been trained. In fact, it would seem that had it not been for the unavailability of the other 25% due to various reasons, the figure could have been 100%. The focus of the training was the MP, HCFC-22 import control, the prevention of illegal trade and the use of refrigerant identifier.

Furthermore a border dialogue each had been conducted in 2018 and 2019 between Botswana/Zimbabwe and Botswana/Zimbabwe/Zambia respectively as discussed in section 4.6.4. This aimed at discussing how to deal with common border challenges and the possibility of harmonizing legislation and import permits in the region. What remained a challenge were the lack of ODS facilities at the borders as well as the high turnover of trained staff (UNEP, 2019d).

A mandatory educational certification system for technicians has been implemented through the refrigeration and air-conditioning association with the endorsement of the ODS Regulation of 2014. The country also conducted two training workshops which saw 75 technicians trained in good servicing practices, refrigerant recovery and reuse, and safety issues related to servicing refrigeration and air-conditioning equipment using low-GWP refrigerants. The disbursement rate for refrigeration equipment has reached 67%. However, strengthening the regional retro-fitting centres was being hampered by the slowness of the cooperating agency in procuring refrigeration equipment (UNEP, 2018f; 2019d).

Botswana has consequently been in compliance with the control targets set in the greement between the Government and the Executive Committee. This has largely been thanks to the effective enforcement of the licensing and quota system for the control of HCFC imports and exports. It is expected that the activities in the second tranche will further sustain the results so far achieved in stage I of the HPMP.

4.6.6 HCFC-22 phase-out management implementation process

According to the agreement between Botswana and the executive committee of the MLF, the overall responsibility of the management and the implementation of the HPMP and all associated activities lie with the country. The lead implementing agency (Lead IA) in respect of the country’s activities under the agreement with the MLF is UNEP, while the cooperating implementing (cooperating IA) agency is UNIDO. Evaluations of progress are to be carried out under the auspices of the MLF (UNEP, 2018f). The responsibilities of the lead IA are to ensure coordinated planning, implementation and reporting of all activities as agreed with the MLF, including the independent verification of progress. This extends to coordination with the cooperating IA so that implementation activities are appropriately timed and sequenced activities in the implementation. In particular, the lead IA has a mandate of monitoring ODS imports and keep records which are then used as a crosschecking reference in all the monitoring programmes for the different projects within the HPMP. The lead IA, along with the cooperating IA also undertake the challenging task of monitoring illegal ODS imports and exports and advise the appropriate national agencies through the NOU. The responsibility of the cooperating IA is to support the lead IA by implementing the agreed activities (*ibid.)*.

Nationally, ODS control activities are coordinated, monitored and implemented within the framework of the Botswana HCFC phase-out management plan by the NOU. The NOU is mandated to prepare a quarterly progress report for the HPMP project. Independent verification of progress is then conducted by a consultant arranged by the lead IA. The NOO interview results revealed that a number of activities were lined up for implementation for the period January 2018 to December 2020. These include:

- Workshops to train 200 customs officers and 20 environmental inspectors in HCFC import control and prevention of illegal trade.
- Three workshops to train 90 servicing technicians in good servicing practices.
- Completion of the procurement of small servicing equipment for refrigerant recovery, reuse and reclamation for 3 centers of excellence by March 2019.
- Implementation of an end-user incentive programme in connection with the training of technicians in installation and servicing refrigeration and air-conditioning equipment using low-GWP refrigerants.
- Monitoring to ensure effective implementation of activities under the HPMP.

On a positive note, the Country Programme implementation report for 2019 confirmed that the Botswana government has been effectively implementing a licensing and quota system for HCFC-22 imports and exports since 2015, and that the total consumption of HCFCs for 2018 was 8.58 ODP tonnes. The verification concluded that Botswana is in compliance with the targets set out in the agreement between the government and the MLF executive committee (UNEP, 2019d).

4.6.7 Monitoring and evaluation of HCFC-22 phase-out management plan

The monitoring and evaluation of HPMP activities by the country is listed by MLF as one of the critical activity that it must ensure (UNEP, 2020). Interview results with NOO revealed that at the NOU monitor the implementation of the HPMP activities and report on a quarterly basis on project progress to the lead IA. Operationally, the NOU is constituted to carry out the day-to-day monitoring of all sub-projects under the HCFC-22 phase-out management plan and report and advise UNEP on corrective measures to be adopted when necessary. Independent evaluation of proposed projects within the HPMP projects is conducted by a local consultant contracted by the Lead IA. The monitoring process also facilitates re-allocation of funding by the NOU and UNEP as necessary during the implementation process, in line with country-driven approach followed by UNEP (*ibid*.).

4.7 **Conclusion**

The evaluation of stakeholders' level of HCFC-22 knowledge and level of HCFC-22 awareness reveals that, overall, the level of HCFC-22 knowledge and awareness among stakeholders is moderate. This suggests that there are still gaps in information dissemination to key stakeholders and this remains a crucial discrepancy between the country's HPMP success lead indicators and its lag indicators. This discrepancy belies the fact that the bulk of the respondents were relatively well educated (certificate and diploma holders) and experienced (6–15 years). This suggests that there have simply not been enough awareness-raising efforts on the part of BRACA and the other entities charged with this responsibility. Materially successful implementation of the HPMP of Botswana will thus remain a challenge. The existence of significant differences in level of product knowledge and awareness of the HCFC-22 phase-out among stakeholders only serves to corroborate these awareness-raising and information-dissemination gaps, and casts doubts on whether the crucial buy-in exists among all the stakeholders. This remains an area of need in Botswana's HCFC-22 phase-down and phase-out efforts.

Literature and survey results confirm that Botswana has a functional and an effective HCFC-22 phase-out management system. Furthermore, the existence of a functional licensing and quota system, and satisfactory implementation of the resolutions of various meetings of the parties were verified. The result, not surprisingly, was a recommendation to the executive committee of the MLF for wholesale approval of funding for the rest of the first phase (2016-2020). The general trajectory since 2013 has been also one of diminishing HCFC-22 consumption, largely attributed to the robust licensing and quota system, awareness raising activities and various initiatives in the RAC sector.

CHAPTER **5**

BOTSWANA COMPLIANCE LEVEL TO THE MONTREAL PROTOCOL RESOLUTIONS ON PHASING OUT OF HCFC-22

5.1 Introduction

Botswana's HCFC-22 phase-out strategy is defined by strategies agreed by the MP signatories under Decision 54/39 at the XIX meeting of the parties (MOP) (UNIDO, 2015). Hence, Botswana approves a staged approach in phasing out HCFC-22 and thus developed the HPMP and enacted the ODS regulations in the National Meteorological Act, 2014 within the structure of the principal strategy (as discussed in literature section 2.12.1.5). This chapter therefore analyses the second objective of the study, which was to evaluate the level of compliance of Botswana to the MP resolutions on the monitoring, consumption and phasing out of HCFC-22. As discussed in section 2.11.1, different A5 countries have instituted various laws and regulations to control the importation, exportation, consumption and usage of HCFC-22, with the ultimate goal of complete ODS phase-out.

5.2 Alignment of Botswana's HCFC-22 phase-out framework with the Montreal Protocol resolutions

The ODS regulations in the Botswana National Meteorological Act, 2014, were designed in such a way as to cover many of the elements of the MP resolutions. The Botswana ODS regulations, 2014, are mainly concerned with the control measures for the phase-out all HCFC, which include imports and exports, safe storage, transportation and disposal of ODS and the reporting of ODS consumption data to the NOO. However, the Act does not comprehensively regulate the promotion of exchange of information and the transfer of technology; however, these are addressed in the Botswana HPMP. The ODS regulations, 2014, and the National Meteorological Act, 2014, were meant to create a regulatory framework that facilitates the phase-out of HCFC-22 (GoB, 2014a: GoB, 2014b), and the Botswana HPMP was meant to develop an overarching strategy that would permit the country to achieve the reduction levels in HCFC-22 consumption, as agreed by MP members in decision XIX/6 (UNIDO, 2015). The main objective of the Botswana HPMP is to meet the MP requirements of a freeze in HCFC-22 by 2013, a 10% target reduction by 2015 and a 35% target reduction by 2020. The HPMP further details the specific activities that Botswana has planned to undertake to accelerate the phase-out HCFC-22 (*ibid.*).

5.3 Stakeholders' familiarity with the HCFC-22 phase-out strategies

As discussed in section 2.12.1.3, Botswana, through the DMS, developed the HPMP which details the specific activities that Botswana planned to undertake as it phases-out HCFC-22. The success of the HCFC-22 phase-out depends on the extent to which stakeholders are familiar with the phase-out plan. The DMS is supposed to ensure that stakeholders are familiar with the HCFC-22 phase-out management plans. Accordingly, stakeholders were asked if they were familiar with Botswana's HPMP. The results indicate that about 52% of DMS participants indicated that they were familiar with the Botswana HPMP. By contrast, most companies (67%) and most customs officers (85%) indicated that they were not familiar with the HCFC phase-out management plan. In addition, many consumers (75%), who are the end users of HCFC-22, indicated that they were not familiar with the phase-out plan prescribed in the Botswana HPMP. The knowledge gaps related to the existence of the HPMP per se, the various restrictions and provisions imposed by the HPMP and the supporting Acts and regulations. Interview results and the NOO revealed that the Botswana HPMP has not yet been introduced in the public domain; hence stakeholders are limited to the contents of the document. Key to the implementation of the phase-out plan is the Botswana HPMP, the National Meteorological Act, 2014, and the ODS regulations contained in it. The stakeholders were then asked if they were familiar with the National Meteorological Act, 2014 and the ODS regulations, 2014. Of those who indicated that they were familiar with the phase-out plan, less than half of customs officers (47%) and consumers (35%) indicated that they were familiar with the provisions of the National Meteorological Act of 2014 regarding the phase out of ODSs. Study results indicate that 68% of DMS participants and 55% of companies were familiar with the provisions of the National Meteorological and the ODS regulations. Observation results revealed that five (55%) out of nine importers of HCFC-22 possess both the National Meteorological Act of 2014 and the ODS regulation. This shows that whilst some were familiar with the phase-out plan, a significant number of stakeholders were not familiar with the Act that regulates ODSs.

5.4 Stakeholders' perspective on compliance with the ODS regulations and the implementation of the phase-out plan

Stakeholders are expected to comply with the provisions of the following ODS regulations: National Meteorological Act of 2014 (GoB, 2014a), Ozone Depleting Substance Regulations of 2014 (GoB, 2014b); Botswana Strategy for Waste Management of 1998 (GoB, 1998) and and to fully implement the HPMP. The key stakeholder in the implementation and coordination of the HCFC-22 phase-out strategies is the DMS (as discussed in literature section 2.12.1.5). This means that the department must comply with regulatory and non-regulatory measures aimed at ensuring effective phase-out of HCFC-22. The study assessed the extent to which the DMS implements the regulatory and non-regulatory measures. Firstly, the DMS was asked about the extent to which it complies with and enforces the ODS regulations as contained in the Act. Most DMS respondents (76.5%) believed that their level of compliance to the ODS regulations was moderate, with only 23.5% believing that their level of compliance was low. A further analysis of the DMS perspective was undertaken to find out the extent to which the department is complying with or enforcing the specific key provisions of the National Meteorological Act, 2014, the ODS regulations, 2014, and the Botswana HPMP. The results are shown on Figure 5.1.

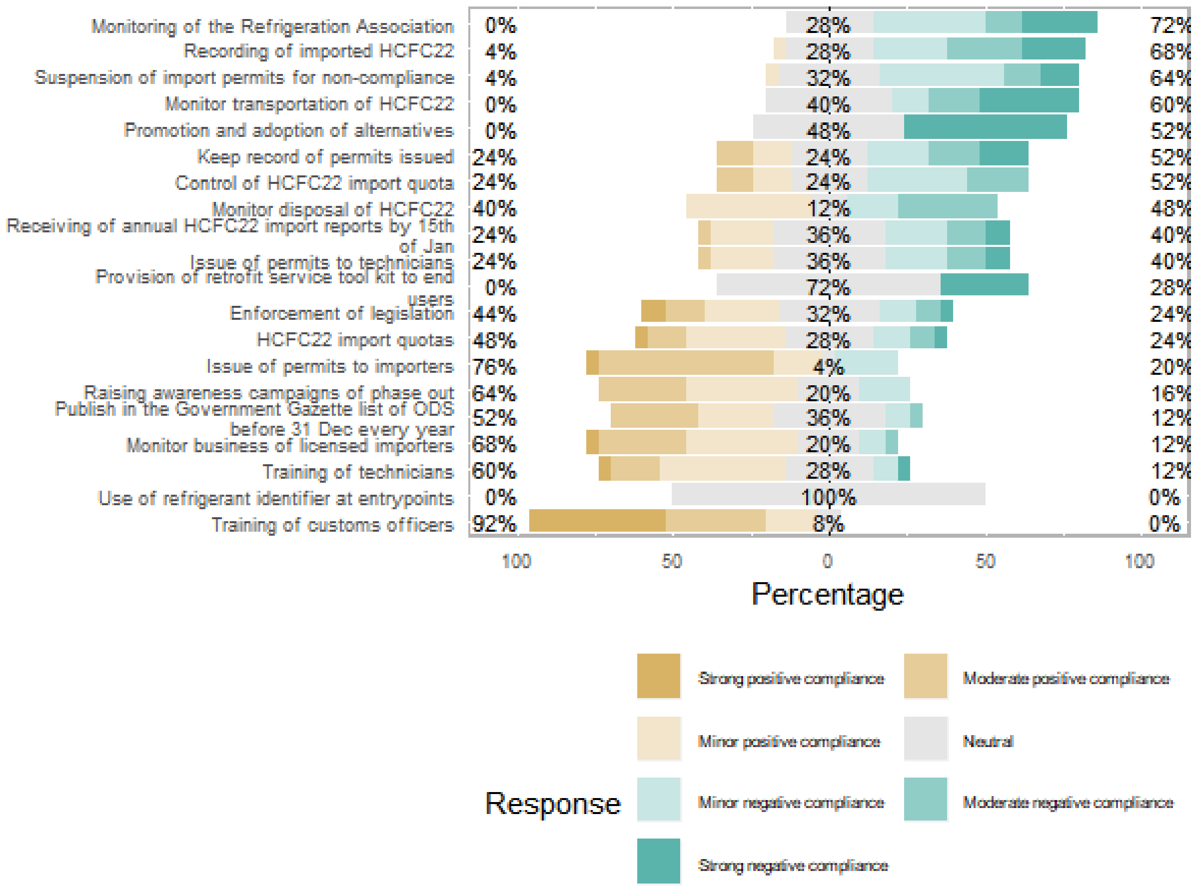


Figure 5.1: The DMS perspective on level of compliance to the HCFC-22 phase-out strategies

Figure 5.1 shows that the DMS largely complies with non-regulatory elements of the phase-out plan that include training of custom officers (92%) and technicians (60%). Regarding the regulatory elements of the phase-out plan, the DMS has been more compliant mainly in terms of issuing permits to importers (76%) and monitoring licensed businesses (68%). However, the department has been less compliant when it comes to monitoring transportation (0%), the use of gas identifiers at entry ports (0%), the provision of retrofit kit to end users (28%) and control of ODS imports (24%).

Like the DMS, other stakeholders which include companies/importers, customs officers and consumers should comply with the National Meteorological Act, 2014, and the ODS regulations, 2014 for the effective phase-out of HCFC-22. Stakeholders were also asked about their level of compliance to the National Meteorological Act of 2014 and ODS regulations, 2014. About 67% of companies indicated that their level of compliance was moderate, with only 33% indicating that their level of compliance was low. This is in contrast to customs officers and consumers, with 46.4% and 51.5%, respectively, thus indicating that their level of compliance was low. This shows that compliance is perceived to be relatively high among DMS and companies/importers and low among customs officers and companies.

5.5 Control and monitoring of HCFC-22 imports

According to the DEA (2018a), the control and monitoring of the HCFC-22 imports/exports in the country is expected to result in a decrease in consumption to levels agreed by the MP. Control and monitoring of HCFC-22 imports mainly start at the country's entry ports. The survey indicates that Botswana has 26 entry points which include two airports and 24 border posts (Figure 3.1). The results of the study indicate that most of the companies (66.7%) import HCFC-22 refrigerant from SA and only 33.3% is imported from China. About 66.7% of the companies import the refrigerant using Tlokweng Gate border post. A few companies, constituting 22.2% and 11.1%, mainly use the Pioneer border post and the Lobatse border post respectively. As discussed in the literature review (section 2.12.1.4), to control and monitor HCFC-22, the National Meteorological Act of 2014 imposed licensing requirements, quotas on imports and accurate reporting of consumption of HCFCs. The subsequent sections present and explain the results of the monitoring and control of HCFC-22.

5.5.1 Issuance of import licences

As a measure to keep track of imports of ODSs, the NOO was to issue import licences to importers of these substances. As discussed in the UNEP (2015a; 2018a), an import licence legally allows specific companies to import ODSs. Accordingly, any company or individual without an ODS import licence would not be allowed to import ODS into the country. The DMS indicated that certain importers have been issued with an import licence and that there are ten companies in the country legally allowed to import ODSs. The researcher verified such claims by visiting each of the companies to find out whether they indeed had import licences for ODSs. Observation results indicate that indeed all (100%) companies had import licences. The import licence is used by the customs department to identify importers at each entry point. However, it may be possible that there are some other companies unknown or omitted by the DMS who could be importing ODSs without import licences. To investigate that possibility the researcher used the snowballing method to find other possible companies which may not exist on the list. During the survey of the nine ODS importers, the researcher asked them to mention other importers of ODSs that they are aware of. No single company in the survey mentioned any other company that was not on the list of ten companies provided by the DMS. This implies that the list provided by the DMS was a true reflection of the situation and that all importers of ODSs possessed import licences. The licensing system was therefore, at the time of the study, comprehensive and all-encompassing and in conformity to the requirements of the MP. Elsewhere, two of Botswana's neighbours, Zimbabwe and SA, fared equally well and better in this case. Hence, Zimbabwe's and SA's licensing and quota systems are fully functional, with the former having issued quotas for 2018 and 2019 to its 47 importers under the ODS regulations. However, there remain funding challenges to following up importers to ensure that they submit returns (UNEP, 2019d). Similarly, SA's DEA (2016) reports that import quotas were allocated to all pure and blended HCFC importers. Botswana thus continues to fall short in implementing and enforcing the quota system, and this means HCFC-22 figures currently reported might be an understatement of the status quo.

5.5.2 Import quota restrictions

As agreed by the parties to the MP, the NOU is supposed to ensure that consumption levels of HCFC-22 are reduced. The milestones are a target reduction of 10% by 2015 and 35% by 2020, as discussed in the literature (section 2.9). To reduce consumption levels, importers are supposed to adhere to a strict import quota system. An import quota system requires limits to the physical quantities of HCFC-22 that can be imported into the country. Interview results from companies show that Botswana implements an industry-wide quota system. The country restricts the quantities of ODS imports for the whole group of nine companies that participated in the study, including the tenth company which did not participate in this study. Interview results from the NOO revealed that there are no import quota restrictions for individual companies but that they cover all the companies. This has been corroborated by the UNEP (2019d), which describes consultation on the allocation of annual imports by the Licensing Committee and recommendations by the same committee on the total quota for the coming year. The key challenge remains industry's inertia in applying for permits, with compliance happening when they have been turned back from the ports of entry. Elsewhere, Namibia has a functional quota system, with all HCFC importers and exporters of HCFCs thus far (2019) registered and given individual HCFC quota allocations (UNEP, 2019d). Botswana still has a lot to learn from Namibia, which aims to phase out HCFCs in 2020, and has seen its quotas steadily decline, giving rise to challenges in awarding the same to new upcoming companies. In particular, the researcher believes the absence of individual company quotas remains a glaring weakness requiring rectification in the current quota system.

Study results revealed that individual ODS importers are asked to reduce their annual imports by a percentage in order to meet the targeted milestone for that year. The NOU has encouraged ODS importers to use stepwise HCFC-22 reduction as discussed in the literature (section 2.12.1.2). The expectation is that adherence to target consumption reductions by all individual companies will result in industry-wide reduction in consumption. The survey results indicate that all importers (100%) adhere to the import quota restrictions, which are set by the NOU on an annual basis. Interview results revealed that companies that import HCFC-22 from SA are affected by SA's ODS policies on consumption of the refrigerant. This result in importers of ODS adhering to their quota allocation. The study results also revealed that there are no policies that restrict HCFC-22 imports from China.

The industry-wide approach seems to be reasonable on the face of it. However, it has weaknesses. Whilst industry-wide targets can be met, this lacks fairness. There are no mechanisms in place to ensure that companies are adhering to the import quota requirements at the individual level. This means that Company A may adhere to the import quota restrictions, whilst Company B may not. In the end there will be no incentive for Company A to meet the quota which Company B is adhering to.

The UNEP (2019d) cites Zambia as another example in the Southern African region of how to manage a quota system in line with MP resolutions. The country has an individual importer-based quota system, with the quotas determined by the National Ozone Committee. Outside the region, as discussed in the literature review, section 2.10.1.2, Singapore also has an individual importer-based, confidential quota system, with the quotas transferable upon request and approval twice a year (Yin, 2012). Botswana's quota system therefore still lags behind regional and international best practices.

When importers reach the port of entry, they are supposed to produce the import licence with the allocated quota, which shows the specific amount they are supposed to import per period. However, this is not currently happening. In the survey, all the custom officers (100%) indicated that they do not have import quotas for each licensed company. Importers of ODS identify themselves using ODS import licences. The custom officers (100%) indicated that they also do not have a list of companies that are allowed to import ODS and they have to rely on the import licences that importers produce at the entry points. They also indicated that they do not use custom codes to track the quantity of imports, which makes it difficult to track and monitor the entry of HCFC-22 into the country. The NOO and the principal BURS officer indicated that the NOU is responsible for providing HCFC-22 quota information to custom officers through BURS.

5.5.3 Estimation and reporting of HCFC-22 data

Another important requirement of the MP resolutions in controlling and monitoring HCFC-22 imports is the accurate collection, estimation and reporting of ODS consumption data. The country is required to report accurate data on HCFC-22 consumption to the UNEP. The amount of HCFC-22 imported into the country is recorded at points of entry. Furthermore, the importer companies are required by the 2014 ODS regulations to report ODS consumption data to the NOO within 14 days of making a sale. Study results reveal that importers submit HCFC-22 consumption data to the NOO at the end of the year. This shows that all (100%) importers of the HCFC-22 are not compliant with the ODS regulation. Figure 5.1 indicates that the DMS negatively (40%) complies (i.e do not comply) with receiving annual reporting of HCFC-22 consumption by 15th January every year. The UNEP's (2019d) annual report indicates that Botswana's data was successfully submitted for 2016 and 2017. However, there were discrepancies arising from late submission by importers and some of the customs department data were captured and classified under the vague category of "other", which made verification difficult.

Table 5.1: HCFC-22 consumption for the period 2013–2017 reported to the UNEP

	Year				
	2013	**2014**	**2015**	**2016**	**2017**
HCFC-22 consumption (kg)	197 000	190 000	176 300	170 600	156 000

Source: Survey data

Table 5.1 shows that the NOO is up to date with the reporting of data to the UNEP. Whilst the NOO seem to be up to date with the requirement to submit annual consumption of HCFC-22 to the UNEP periodically, there is need to evaluate the accuracy of the data submitted by the NOO to the UNEP. In order to assess the accuracy of this data, the researcher analysed the HCFC-22 consumption data reported to the NOO by importers and customs (BURS) – the data are summarised in Figure 5.2.

Study results revealed that all (100%) HCFC-22 importers reported their consumption data to the NOO, while BURS also reported the imported ODSs to the NOO. The NOO then reports the yearly HCFC-22 consumption to the UNEP. There is therefore supposed to be no difference between importers, BURS and NOO data reported to the UNEP. Figure 5.2 indeed shows that there is no significant difference between companies' HCFC-22 annual consumption data and NOO reported data.

All HCFC-22 used in Botswana is imported from SA and China. As a result, the reported company data and NOU data should be equivalent to BURS data. However, Figure 5.2 shows that there is a wide difference between customs/BURS data and NOO data, and between BURS and company data. BURS figures are much lower than those reported by companies and the NOO. This shows that the Botswana data reporting and collection system lacks accuracy. These reporting discrepancies also bedevil other countries in the region, including Angola, Zambia and Namibia (UNEP, 2019d). In fact, Koegelenberg and the DEA (2019) lament that in most SADC countries there are significant observed discrepancies when comparisons of reported import and export data from countries are made. The common trend, they report, is that importing countries report significantly lower figures of HCFC-22 than are declared by the exporting counties. They cite as some of the possible reasons for these discrepancies, among others, illegal trade, wrong or false application of licensing, selective recognition of trade in ODSs by different countries, and lack of regular reconciliation of data among the NOU, customs department and licensing authorities.

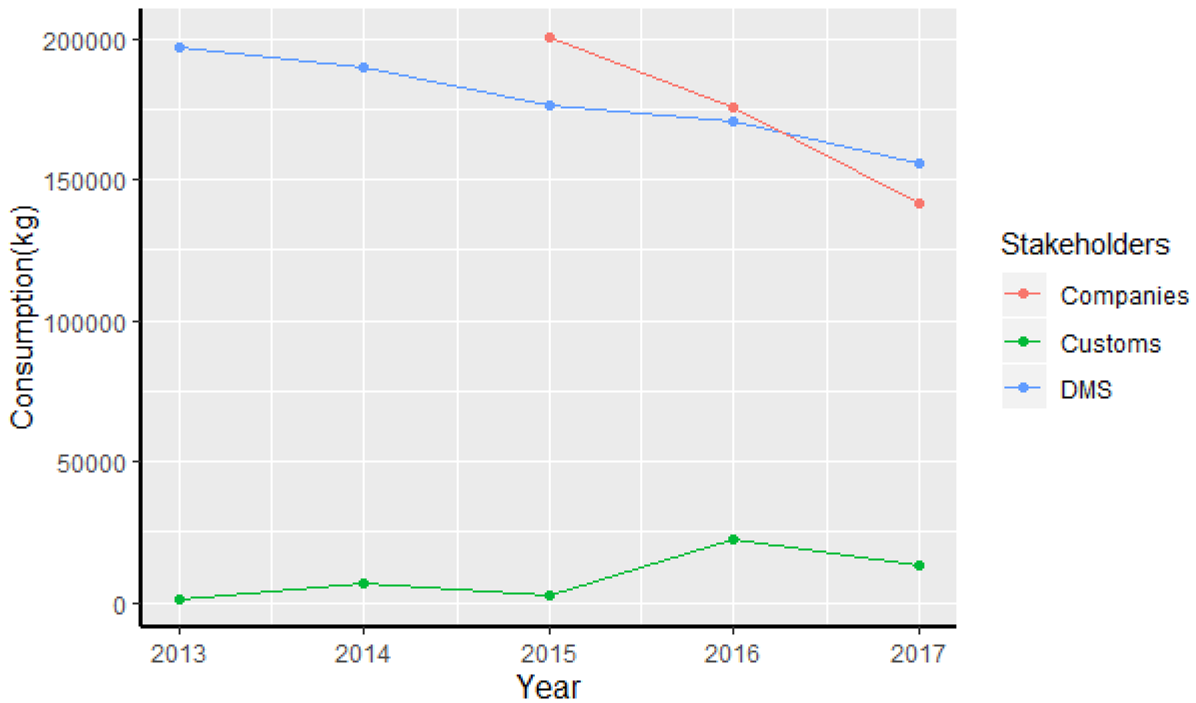


Figure 5.2: Comparison of reported consumption of HCFC-22 by stakeholders

After noting these data reporting differences, the researcher investigated the data reporting systems of HCFC-22 consumption further. Interview results with the DMS revealed that companies report HCFC-22 consumption to the NOU. This means that the NOU relies solely on companies for the HCFC-22 consumption data. This data may obviously be inaccurate. As a result, there is no coordination between quantities of HCFC-22 recorded by BURS, the NOU and the companies that import HCFC-22. There is also no regional or global coordination between exporters of HCFC-22. Moreover, there is no computerised system that captures quantities of HCFC-22 data immediately it is imported into the country. Another notable observation is that due to poor record keeping, importers were only able to provide HCFC-22 consumption data for the period 2015–2017. Other importers experienced challenges in keeping records of their HCFC-22 consumption. In a similar study, Knutson *et al.* (2015) reported inconsistencies in import/export reporting data, with China reporting thrice more HCFCs exported to Costa Rica than received. About 40% of HCFC-22 is smuggled into Costa Rica (*ibid.*).

The study further analysed the 2016 HCFC-22 imports provided by BURS against HCFC-22 exports reported in the South African HFC inventory report (UNIDO, 2017) to check whether the reported consumptions were similar. Figure 5.3 presents the results:

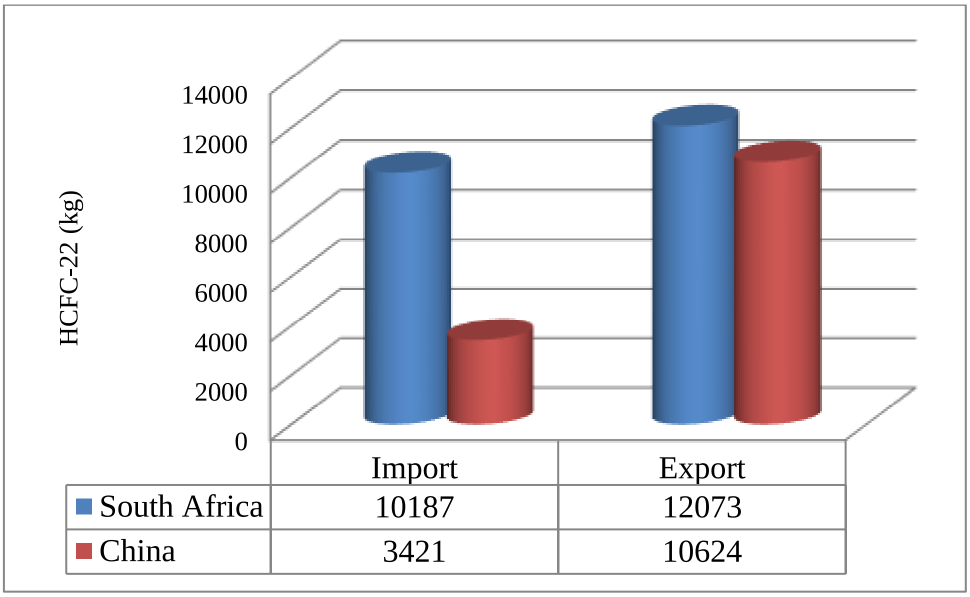


Figure 5.3: 2016 HCFC-22 imports and exports

Source: Survey data and UNIDO (2017)

The results displayed in Figure 5.3 indicate a big difference in reported import and export data (7 203 kg) from China and a small difference in data on imports and exports (1 886 kg) from

South Africa. A notable difference exists between HCFC-22 consumption reported by the NOO in 2016 (170 600 kg) and the reported imports and exports (Figure 5.3). These anomalies indicate some gaps in reported consumption. The study results reveal that the NOO has asked for HCFC-22 consumption from BURS in paper form, and that challenges were experienced when it comes to classifications of HCFC codes.

5.5.4 Physical checking and monitoring of HCFC-22

Physically checking and monitoring HCFC-22 is important for efficient import controls and to prevent smuggling and illegal trading. The study results revealed that when HCFC-22 reaches the port of entry, it is physically checked by customs officials. However, customs officials only do eye checks. The results reveal that there are no refrigerant identifiers that are used to accurately detect the type of refrigerant gas passing through the ports of entry. Likewise, the questionnaire results reveal that all customs officers (100%) confirmed that they were currently not using refrigerant identifiers at the points of entry. According to the DMS, there were only three refrigerant identifiers available for use at the country's entry points. However, interview results further revealed that these three identifiers have not yet been distributed to the ports of entry for use by customs. Moreover, the identifiers are too few considering that there are at least 26 ports of entry in the country. A recent report by Letsholo (2019) indicated that the DMS gave eight refrigerant identifiers to BURS with the intention of fighting the illegal importation of ODS. This has resulted in the country having a total of 11 refrigerant identifiers which will be distributed to Botswana ports of entry. A similar report was given by the Government of India (2017) where 28 refrigerant identifiers were supplied to customs officers to prevent illegal trade in ODSs at ports and border checkpoints.

Without the use of refrigerant identifiers, it is possible that more HCFC-22 may be entering through the ports of entry than is required. Moreover, customs officers only check HCFC-22 refrigerant cylinders that are used for servicing the already existing equipment. They do not check the amount of HCFC-22 that is in new equipment, like air conditioners. The expectation is that there is no new equipment that is using HCFC-22 being imported into Botswana (as discussed in section, 2.12.1.1). It is assumed that the HCFC-22 imported into the country in gas cylinders is only used to service existing HCFC-22 equipment (UNIDO, 2015; UNEP, 2019d). It is important to check ODSs both in gas cylinders and in any potential equipment containing HCFC-22. However, it seems that there is no thorough checking of equipment that might possibly carry ODSs. Customs officers were asked how they monitor ODS equipment imported into the country. Consequently, about 65% indicated that there is no strict monitoring of ODS equipment imported by companies. An even higher proportion of custom officers (75%) indicated that there is no strict monitoring of ODS equipment imported for personal use. Without strict monitoring of ODS equipment imported into the country, ODS imports are likely to find their way into the country through illegal trade (section 2.11.1). About 83% of the custom officers indicated that there are no strict measures in place to prevent the possible illegal trade in ODS in the country. China, one of the biggest producers and exporters of ODSs, has an excellent ODS import and export monitoring system that may be worth emulating (UNEP, 2019f). The system, called the ODS Import and Export Management Online Approval System, enables the tracking of the licence and permit approval and clearance process and makes real-time trade information available such as destination countries, ports, actual ODSs and their quantities, and so on. This has been complemented by the capacitation of enforcers through training, the provision of equipment like ODS detectors and more rigorous inspections. Botswana still lags behind in almost all the above respects, and as noted elsewhere, there is a discrepancy between these lead indicators of the country's MP success and its reported lag indicators.

When asked what measures were in place to control the illegal trading of HCFC-22, study results indicate that customs officers do physical checking of refrigerants since there are no refrigerant identifiers and they rely on import permits. In response to the same question the DMS respondents mentioned that the use of the ODS import permit, training of customs officers and the use of the ODS regulation are the measures put in place to prevent illegal trading of HCFC-22. The NOO further explained that importers were supposed to produce an import permit at the port of entry when declaring their goods; if they failed to do so they would not be allowed entry pending application and production of the import permit. However, the implementation by BURS was deferred pending training of customs officers at ports of entry. Without the use of refrigerant identifiers at ports of entry, tight control of HCFC-22 movements is compromised.

As a measure to control and trace imports of HCFC-22 supplied to consumers, the ODS Regulations of 2014 require that importers should keep a record of names and addresses of entities to whom the ODSs have been supplied. Study results indicate that 55% of importers keep the records and 45% does not keep records. The ODS regulation further requires importers to cause the person who buys controlled substance to sign a declaration form. The study results revealed that 22% of importers require consumers to sign a declaration form while 78% do not comply with the regulation. This claim was supported by 28% of consumers who claim that they fill in the declaration form, while 72% stated that they do not sign any declaration form upon purchasing HCFC-22. These results indicate that there is a gap in the monitoring of HCFC-22 imported into Botswana.

5.6 Training, public awareness and promotion of use of alternative technologies

The HPMP requires Botswana to meet its HCFC-22 phase-out obligations through the training of customs officers and refrigeration service technicians and promoting the use of alternative technologies and awareness programmes (UNIDO, 2015). This section presents and discusses the results on the way training and promotion of the use of alternative technologies and awareness programmes are carried out.

5.6.1 Training of customs officers

As discussed in section 5.5, Botswana's consumption of HCFC-22 relies on imports. As such, customs officers need to be conversant in the regulatory procedures for controlling, identifying and monitoring HCFC-22 imports and HCFC-22 dependent equipment. For effective implementation of the ODS regulations on control of HCFC-22 imports it is important that customs officers are trained in the handling, detection and identification of ODS and equipment containing them and their importation procedures. UNIDO (2015) mentions that training of customs officers and other important law enforcers, as well as establishing customs officers' training programmes, is one of the main activities proposed in the HPMP.

Training of customs officers is expected to increase their level of awareness of the impacts of HCFC-22 on the environment and improve consistency of recorded data on HCFC-22 and equipment. The study evaluated whether customs officers received training on handling ODS at Botswana ports of entry and when they received the training. Of the 65 customs officers surveyed, 68% indicated that they had never received any training on the handling of ODS, while only 32% indicated that they had received some training. This shows that the majority of customs officers manning the country's ports of entry may have limited knowledge on the handling of ODSs, which they are supposed to control. The results discussed in section 4.3.3 indicate that customs officers' level of HCFC-22 knowledge was moderate. Without proper knowledge on ODSs, customs officers may lack the effectiveness needed to control the import of ODSs into the country.

Of further interest in the study was the period during which training was provided to customs officers. The majority of customs officers (79%) indicated that they received training in the importation and handling of ODS during 2016–2017. The remaining 21% indicated that they received training during 2010–2011. Firstly, the results indicate that training of customs officers is not being undertaken frequently. As noted, it was only done in the early years of the implementation of the phase-out plan, that is, during 2010 and 2011. After that, customs officers received training during 2016–2017. This means that there was a period of five years during which customs officers did not receive training. Consequently, new employees may have joined the Customs Office during that period and as such may be lacking knowledge of ODS. Furthermore, current employees require refresher training courses so that import controls remain effective. Therefore, holding training more frequently would help in maintaining effective import controls. For its part, China, through its general administration of customs, conducted a total of 24 training workshops spanning 14 local customs in key customs districts between 2012 and 2018, with 2000 customs officers being trained in the process. This, coupled with supplying customs with the necessary equipment, meant there was more thorough inspection, testing and effective detection (UNEP, 2019f). Botswana seems on course in its training targets for stage I up to 2020, having started training activities in 2016 at the rate of 25% trained per year.

The UNEP (2019d) further reported that Botswana's training of customs and law enforcement officers has almost been completed with at least 75% at all entry ports. However, as previously noted in section 5.5.4, ODS detectors are still woefully inadequate, with only 11 reported to be available against 26 entry ports. Similarly, closer to home, Namibia, Zimbabwe and Zambia have been conducting training of customs officers; however, challenges ranging from a lack of funding (Zimbabwe) to high staff turnover in the customs division continue to hamper training efforts. Zambia, for example, managed to conduct only three training workshops, with 45 customs officers receiving training, while Zimbabwe managed to carry out two workshops jointly with its neighbours during the same period (UNEP, 2019d). These remain inadequate against MP requirements, especially as compared to Namibia's figure of 260 customs officers trained (*ibid*.).

Secondly, the results indicate that more customs employees were trained during 2016–2017 than were trained in the early years of HCFC-22 phase-out implementation. This shows that a large number of customs officers were only trained recently. To improve the effectiveness of import controls, a large number of customs officers should have been trained during the early years of the implementation of the HCFC-22 phase-out plan, rather than during the later years. However, the low number of trained customs officers in the early years may be due to the fact that there are few current employees who were with the organisation during the early years. If that is the case, then it would still be important to train customs officers more frequently to cater for new employees joining the BURS department. Training of customs officers is further necessitated by the fact that all HCFC-22 consumed in Botswana is imported, hence being chiefly reliant on customs inspection procedures at entry ports.

5.6.2 Training of technicians in servicing and repair of HCFC-22 equipment

As discussed in the literature review (section 2.10.2.3), incorporating technician training and certification into legislation is an effective way to guarantee the proper handling of ODSs and emission reductions. The National Meteorological Act, 2014, and the ODS regulations prohibit individuals without a permit from servicing or repairing ODS equipment. Under the ODS regulations, the DMS is supposed to train and issue permits to technicians who service ODS equipment. According to UNIDO (2015), the HPMP also proposes that technicians should be trained in good refrigeration practices which include hydrocarbon technologies and retrofit practices. The training is expected to encourage the adoption of alternative equipment that has high energy efficiency with low GWP. Since the beginning of the phase-out, the DMS has indicated that more than 300 permits have been issued to technicians from both the public and the private sector (section 2.10.2.3).

The number of technicians issued with permits appears to be low. As discussed in the literature review (see Table 2.5), there was an estimated 226 240 pieces of ODS equipment in Botswana as of 2010, which means the technicians per unit of ODS equipment ratio is very high, considering also that there could be more HCFC-22 equipment added to the reported number. The number of permitted technicians may therefore be too low given the number of ODS equipment still active in Botswana. This means technicians without permits may be servicing and repairing ODS equipment. This corresponds with UNIDO’s (2015) report that more than 600 servicing technicians were located in the informal sector.

Specifically, the UNEP (2019d) reports that Botswana conducted training of 45 technicians in 2017–2018, in the form of workshops conducted in the north-eastern and the south-eastern parts of the country. The training was focused on government departments and private businesses. Training initiatives also saw 33 technicians from Debswana mine and six from private companies being trained in February 2019 (*ibid*.). Elsewhere, the Coast Rica case indicates some of the major challenges relating to the training of technicians. As in Botswana, a major gap exists in the training of informal technicians in the RAC sector. Knutson *et al.* (2015) report that although regulations exist with regard to certifying technicians and ensuring they do not to emit refrigerant gas, enforcement in the form of tracking the actual certification of technicians is non-existent. This remains for both countries yet another deficiency vis-à-vis the MP requirements that all technicians in both formal and informal sectors be trained.

The study corroborated this issue. To further find out if only trained and authorised technicians are servicing and repairing ODS equipment in Botswana, consumers and companies were asked whether they were making use of technicians to service and repair ODS equipment. Most companies (67%) that are responsible for the selling and distribution of ODS indicated that they were using technicians with permits to repair and service ODS equipment. However, most consumers (54%) indicated that they were not using technicians to service and repair such equipment.

Of the consumers who indicated that they make use of technicians, 67% indicated that the technicians they use do not possess permits. In contrast, only 33% of the companies indicated that they do not use technicians with no permits. This shows that most technicians being used by consumers to service ODS in the country do not have permits, contrary to regulations aimed at ensuring phase out of HCFC-22 and other ODSs. Literature on such efforts in India revealed that the training of technicians was done by 15 training partners each with a minimum of three trainers spread across the country to allow for maximum geographical coverage. This had resulted in the training of 11 000 RAC servicing technicians in 408 training sessions. These technicians were trained in good servicing and installation practices (Government of India, 2017).

5.6.3 Exchange of information on HCFC-22 phase-out

To accelerate the phase-out of HCFCs, the MP implores parties to the treaty to promote exchange of information among stakeholders on the phase-out of HCFC-22 (as discussed in literature section 2.10.2.1). According to the HPMP, all stakeholders and the public in general should be sensitised about the country's plans to phase-out HCFC-22 (UNIDO, 2015). In 2011, as part of the country's application for MLF for the HCFC-22 phase-out programme, Botswana indicated that it would undertake awareness raising programmes and sensitisation workshops on HCFC-22 phase-out (UNEP, 2011a; 2015a).

Awareness programmes are promoted using the RAC association. Study results indicate that Botswana is in line with the MP resolution of establishing RAC association. The results also show that members of the BRACA include ODS distributor companies, customs officers, technicians, refrigeration lecturers from technical colleges and fire fighters. However, when stakeholders were asked if there was a RAC association in Botswana, only seven out of nine (78%) importers were aware of the existence of BRACA. The results also show that approximately 70% and 40% of customs officers and DMS, respectively, were not aware of the existence of BRACA. The UNEP (2019d) highlighted that the slow growth of BRACA is because the majority of its members are from the private sector and are generally very busy. This also explains why some stakeholders are not aware of BRACA's existence.

According to UNIDO (2015), BRACA's main roles are to share information among stakeholders on ODS phase-out and to coordinate the country's training programmes in conjunction with NOO. Study results indicate that sharing of information is done by undertaking various meetings, workshops and conferences for members and the public. The results also revealed that awareness programmes are ongoing and the following activities have been carried out since the phase-out of HCFC-22 started in 2013: media (newspaper, radio and television) campaigns, conferences, workshops and the yearly celebration of International Ozone Day and other observed environment-related days ensure that awareness is raised among the public regarding ozone issues. Capacity has also been built in different committees responsible for ozone monitoring, for example the Licensing Committee. The Botswana NOU and the UN Environment Economy Division jointly organised and attended the Joint Network Meeting of National Ozone Officers for 54 African countries held in Gaborone from 21–23 May 2018 (UNEP, 2018e). The meeting provided an interactive forum for national ozone officers to develop skills, share ideas and exchange experiences with their counterparts in order to comply with MP resolutions.

Importers and distributors of ODSs are also required to disseminate information on the HCFC-22 phase-out to their customers. According to GoB (2014b), the ODS regulations require importers of ODSs to discuss the phase-out of HCFCs with their suppliers as an awareness programme. Suppliers are supposed to inform end consumers that HCFC-22 is being phased out and that they should be prepared to switch to alternatives. Some companies (45%) indicated that they had discussed phase-out with their consumers, while others (55%) indicated that they had not discussed the phase-out of HCFC-22. On the other hand, a slight majority of end-user consumers (65%) indicated that they had discussed phase-out with their suppliers. This means that some companies may be failing to complement DMS efforts to disseminate information about the phase-out of HCFC-22. Observation results noted two (22%) companies who offered awareness campaigns on HCFC-22 phase-out and alternative technology to both their employees and customers. HCFC-22 phase-out awareness campaigns are scheduled during morning briefings with workers and for customers campaigns are done every time they buy HCFC-22 refrigerant. Dates of when the awareness campaigns were conducted were well documented by the two companies that offer HCFC-22 awareness campaigns.

5.6.4 Promotion of research and transfer of technology

An important part of the MP resolution is research and to facilitate the transfer of technology, especially to environmentally friendly alternatives to HCFC-22. The Botswana's HPMP integrates the promotion of adopting HCFC-22 alternatives as one of the main activities of the phase-out plan (UNIDO, 2015). The researcher therefore assessed Botswana's efforts to promote the adoption of alternative technologies. Study results revealed that the DMS promotes the adoption of alternative technologies such as R410A, R404A, R407C, R290 and R507 through research and the public awareness programmes and end consumers are encouraged to replace their old HCFC-22 equipment with alternative equipment using these substances. Dovetta *et al.* (2016) and Kalla *et al.* (2018) suggest R410A as the best substitute option for air conditioning appliances, while R507 and R404A are the best substitutes for refrigeration appliances. As discussed in the literature review (section 2.10.3), through the assistance of the MLF many countries have embarked on research and have switched to HCFC-22 alternatives. However, the problem is that there is no legislation that bans the importation of HCFC-22 equipment into Botswana. The existing legislation controls the importation of HCFC-22 itself for servicing and repair purposes, which still encourage end consumers to continue to purchase HCFC-22 equipment.

To promote research and the transfer of technology, the government of China collaborates closely with pertinent industrial associations in data surveys of ODS-related enterprises, research on alternative technologies and design of sector HCFC-22 phase-out roadmaps. The industrial associations are responsible for the provision of technical consultancy in project development and make suggestions to pertinent departments in the preparation of sector polices (UNEP, 2019a). In Botswana, the UNEP (2019d) reported that some sensitisation workshops were facilitated for RAC technicians on HCFC-22 substitutes and the safe use of HFCs and their alternatives. The report further highlighted that Botswana has not yet conducted a study on the penetration of HFC substitutes in the market.

For end consumers to be able to switch to alternative HCFC-22 equipment, they should have information about the alternative technologies. All companies (100%) were aware of the alternative technologies for HCFC-22 that they were supposed to switch to. They indicated that they were being encouraged to switch to R410A, R134A, R507, R290 or R404A. However, only 65% of end consumers indicated that they were aware of the alternative technologies they could possibly switch to. This shows lack of information among end users about the alternative technologies they needed to switch to, which might slow down their rate of switching to these technologies.

Results discussed in section 5.6.3 show that companies had made efforts to discuss HCFC-22 phase out and the use of alternatives to HCFC-22 with their customers (end users). Of the end consumers who indicated that they were aware of the available alternative technologies, 70% indicated that they were concerned about the high cost of replacing their current HCFC-22 refrigerant systems. Approximately 85% of the end consumers also indicated that they were concerned about the high cost of alternative technologies as compared to HCFC-22 equipment, which will make servicing and repair of refrigerants more expensive. Thus, concerns about the replacement costs and the servicing and repair costs are also some of the impediments slowing down the switch over to alternative technologies.

5.7 Transportation, storage and disposal of HCFC-22

In accordance with the National Meteorological Act of 2014, ODSs should be transported, stored and disposed of in an environmentally friendly manner. The ODS packages should be sealed to avoid leakages and clearly labelled for identification purposes. The researcher inspected the way in which the importer companies package, store and transport HCFC-22. The results are shown in Table 5.2, indicating that most importers comply with the storage, packaging and transportation requirements for HCFC-22. The observation results further revealed that the stacking and storage practices were good for all (100%) companies, although there were no ODS warning signs.

Table 5.2: Storage, packaging and transportation requirements of HCFC-22

Storage, packaging and transportation requirements	Number of companies	
	Yes	No
Storage area properly labelled with ODS warning signs	0	9
HCFC-22 packages sealed	9	0
Presence of fire emergency equipment accessible and visible	9	0
Presence of leak detector to test HCFC-22 leakages	2	7
Presence of ODS inspection form/tool	2	7
HCFC-22 packages stored in secure places	9	0
HCFC-22 packages stored in ventilated areas	9	0
Exposure of HCFC-22 equipment to sunlight/hot surface	0	9
HCFC-22 packages transported in an environmentally friendly manner	9	0

According to GoB (2014b), disposal of ODSs including HCFC-22 should be done in an environmentally friendly manner. No person or individual is permitted to dispose of ODSs without liaising with and obtaining authorisation from the NOO. Moreover, there should be a specific waste disposal place for ODSs. This place should enable the retrofit and recovery of HCFC-22 and other ODSs. However, study results indicate that in Botswana there is no disposal centre for ODS equipment. The UNEP (2019d) also confirmed that lack of RAC disposal/destruction facilities in Botswana which had led to stock piling. Study results indicated that equipment with ODSs is disposed into landfills and the interview results revealed that there are no HCFC-22 retrofit and recycling/recovery centres in Botswana. It is also likely that ordinary consumers without knowledge of the HCFC-22 phase-out may be disposing of HCFC-22 equipment in the landfills. This means that there is a high likelihood that the disposal of HCFC-22 and other ozone depleting substances is not being done in an environmentally friendly manner. Therefore, chances are high that all HCFC-22 disposed of in equipment is emitted into the stratosphere, thereby causing ozone depletion and increasing the rate of global warming. In another related study in Costa Rica (Knutson *et al.,* 2015), the country was found to be deficient in ODS destruction technology, resulting in some companies not only stockpiling HCFC-22, but also CFCs from the previous CFC phase-out. This, as in Botswana, remains a cause for concern as there exists a possibility of surreptitious emission of HCFCs by some companies as they seek to appear to be making headway in eliminating HCFCs.

5.8 **Conclusion**

Botswana has no doubt made great strides in implementing its obligations under the MP. Visible deficiencies remain however, especially in regard to the regulatory elements of the HPMP. It is this researcher's stance that a weakness in one or more of the MP pillars weakens the implementation process and detracts from the overall success of the HPMP. It nevertheless appears that Botswana shares quite a number of adverse issues with not only its regional neighbours but also with other Article 5 signatories. This suggests broader general challenges beyond individual signatories; nevertheless, the researcher still believes Botswana can still do much more to be in compliance. It has also been established that there are no import quota restrictions for individual companies, with the country employing an industry-wide quota approach. However, it has been noted that although industry-wide targets can be met, they lack fairness. In sum, the Botswana data reporting and collection system lacks accuracy. Respondents perceived that there were no strict measures in place to prevent the possible illegal imports of ODS into the country.

Although the majority of customs officers had received training, the training programmes were not done frequently and the training of ODS service technicians is lagging behind. Results indicate that awareness campaigns and research on HCFC-22 alternative technologies are ongoing, although some stakeholders have limited knowledge on the best alternatives. It has been established that in Botswana there are no disposal centres for ODS equipment. Therefore, the disposal of HCFC-22 and other ODSs is not being done in an environmentally friendly manner as required by Decision XII/8 of the MP on the disposal of controlled substances.

CHAPTER 6

AN EVALUATION OF THE ACHIEVEMENTS OF THE HCFC-22 PHASE-OUT MILESTONES AND THE IMPLICATIONS OF HCFC-22 PHASE-OUT FOR BOTSWANA

6.1 Introduction

This chapter reports on the findings of the third and fourth objectives: the evaluation of the milestones on HCFC-22 phase-out trends pursuant to the MP summit and the economic, social and environmental implications of phasing out HCFC-22. Parties to the MP are obliged to follow the stepwise reduction of HCFC-22 consumption that was agreed to in Decision XIX/6 (Kozakiewicz, 2012). Additionally, Article 5 countries, including Botswana, seeking support from the MLF for HCFC-22 phase-out after 2012 were to confirm that they have enforceable national licensing and quota systems for HCFC-22 imports. Therefore, the agreed reference level average for the HCFC-22 phase-out was the 2009–2010 baseline, with reductions of 10%, 35%, 67.5% and 97.5% targeted by 2015, 2020, 2025 and 2030 respectively (Fang *et al.*, 2016). In Botswana, the phase-out of HCFC-22 is planned to be largely completed by 2030, with the aim of reducing consumption by 97.5% of the 2009–2010 base level (UNIDO, 2015). The main objective of Botswana's HPMP was to achieve a 10% reduction in HCFC-22 consumption by 2015 and a 35% reduction by 2020. According to the UNEP (2015a), the baseline consumption level in Botswana for the year 2009 was 200 000 kg. To evaluate the achievement of the intended milestones, consumption trends of HCFC-22 by companies were analysed.

6.2 An analysis of overall consumption trends of HCFC-22

The quantities of HCFC-22 imports for the years 2009–2017, when the implementation of the phase out started, were analysed. The results reveal trends in the progress that the country has achieved in its HCFC-22 phase-out strategy. The results in Figure 6.1 show that HCFC-22 consumption declined slightly from 2009 to 2013, with the quantity of consumption declining from 200 000 kg in 2009 to about 197 000 kg in 2013, resulting in a 1.5% decrease. The slight decrease in HCFC-22 consumption is to be expected, as the implementation of the HCFC-22 phase-out plan was in its early years. In relation to the set targets, the UNEP (2015a) states that Botswana met its HCFC-22 consumption freeze target in 2013. After 2013, the quantity of consumption declined slightly to 190 000 kg in 2014, representing a 3.6% decrease. From 2014 to 2015, a decrease of 13 700 kg was recorded which represented a 7.2% decrease in consumption. As Figure 6.1 shows, a sharp decline in 2014–2015 indicates that HCFC-22 phase-out strategies were becoming more effective in reducing consumption levels of HCFC-22. The overall HCFC-22 consumption decrease for the first stage 2013–2015 (190 000 kg to 176 300 kg) was calculated at 10.5%, slightly more than the 10% reduction expected.

One obvious reason for the decline in HCFC-22 consumption was the effects of the implementation of the country's HPMP by the NOU, for which implementation commenced in 2013. This saw some companies begin the importation of HCFC-22 substitutes and coincided with SA's enactment of a raft of legal instruments, measures and controls on the importation, exportation, consumption and use of HCFCs through the regulations. Among these were the Air Quality Act 39 of 2004 which introduced a requirement for import and export licences; the DEA Regulation 33925 of 2011, which established a quota system to restrict HCFC imports to the MP limits starting 1 January 2013; and the National Standard 10147 of 1994 which established a code of practice for the reduction of ozone depleting refrigerant emissions.

The fact that at the same time as Botswana witnessed a reduction in HCFC-22 consumption, SA, the chief source, saw a consistent drop in HCFC-22 consumption hints at a possible influence by SA on Botswana's compliance pattern and conformity. Specifically, the DEA (2018a) puts the SA consumption figures for 2014, 2015 and 2016 at 3558.5 MT, 3155.6 MT and 2581.4 MT respectively, representing decreases of 11.3% for 2014–2015 and 18.2% for 2015–2016. As indicated in section 7.2.1, SA has a functional licensing and quota system and this must, to a large extent, account for its success in reducing HCF-22 consumption. Similar success stories were witnessed in Vietnam, Chile, Malaysia and India, where consumption of HCFC-22 in 2016 was below the established baselines. Chile, Malaysia and India reduced consumption of HCFC-22 by 27.5%, 38% and 37% respectively (UNEP, 2017d). Closer to home, the UNEP (2018c) observes that due to its commitment, Namibia has already reduced its HCFC consumption drastically by 80% from the baseline. The World Bank (2017), Brophy (2016) and the UNEP (2017d) observe that the licensing and quota system as a regulatory measure to control and eliminate ODSs remains the most effective tool for ensuring compliance with the MP and a decline in HCFC-22 consumption.

As agreed at the 19th MoP, Botswana committed to reducing HCFC-22 consumption from 2016–2020 by 35% (UNEP, 2015a). The second milestone was to assess Botswana's progress towards achieving a 35% decrease in HCFC-22 consumption by 2020. The results of this study reveal that from 2015 to 2016 HCFC-22 consumption decreased by 3.25% and from 2016 to

2017 it decreased by 8.6%. Overall, from 2015 to 2017, an 11.5% decrease was recorded. The results also show the progress made in decreasing HCFC-22 consumption towards the 35% target set by the MP by 2020.

In overall terms, the trend line graph is consistently declining from year to year (Figure 6.1). This means that the country's consumption levels of HCFC-22 are declining. Much more importantly, the declining trend implies that Botswana is being consistently successful in reducing the consumption of HCFC-22. The UNEP (2017c) reported similar results, where Namibia's 2016 HCFC-22 consumption was 55% below the baseline for compliance and 11% less than the maximum permissible consumption agreed by the Executive Committee in 2016.

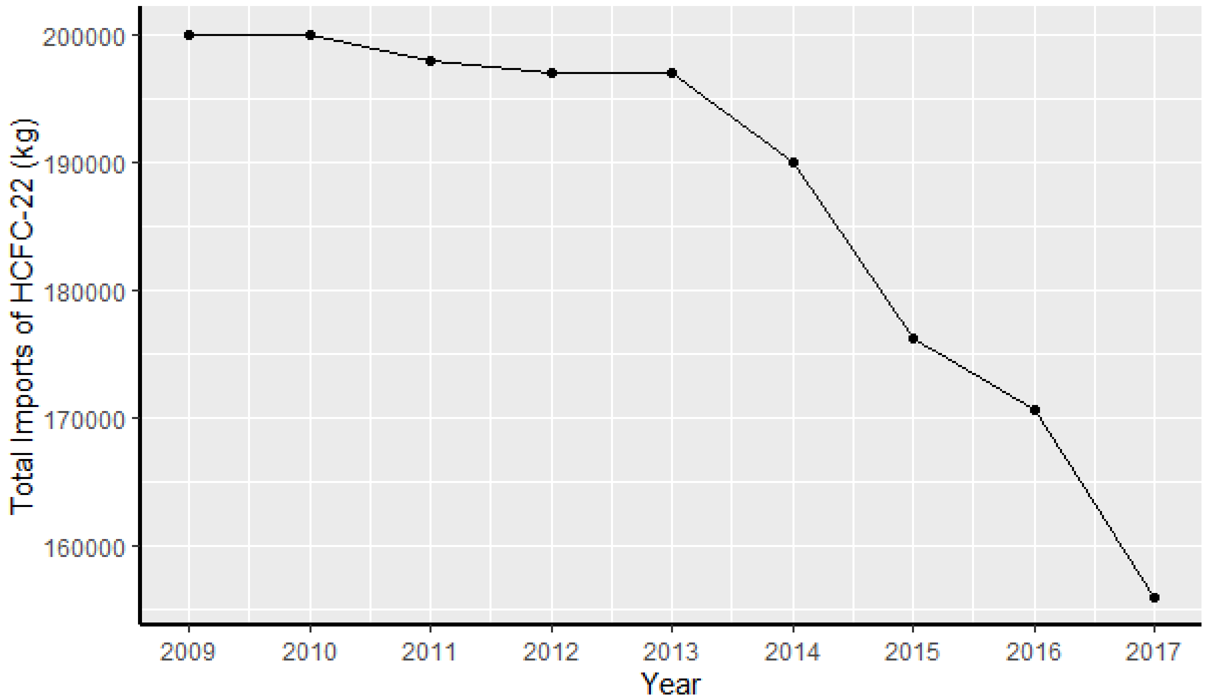


Figure 6.1: Yearly total consumption trend of HCFC-22 from 2009 to 2017 in Botswana

Whilst Figure 6.1 shows that consumption of HCFC-22 is consistently declining, it is important to note that the data used were provided by the DMS, which provides all recorded amounts of imported HCFC-22. In order to verify that the consumption of HCFC-22 was indeed declining, an analysis of the import data provided by each of the companies that import HCFC-22 was done. The total import data covered the years 2015–2017 and is shown in Figure 6.2.

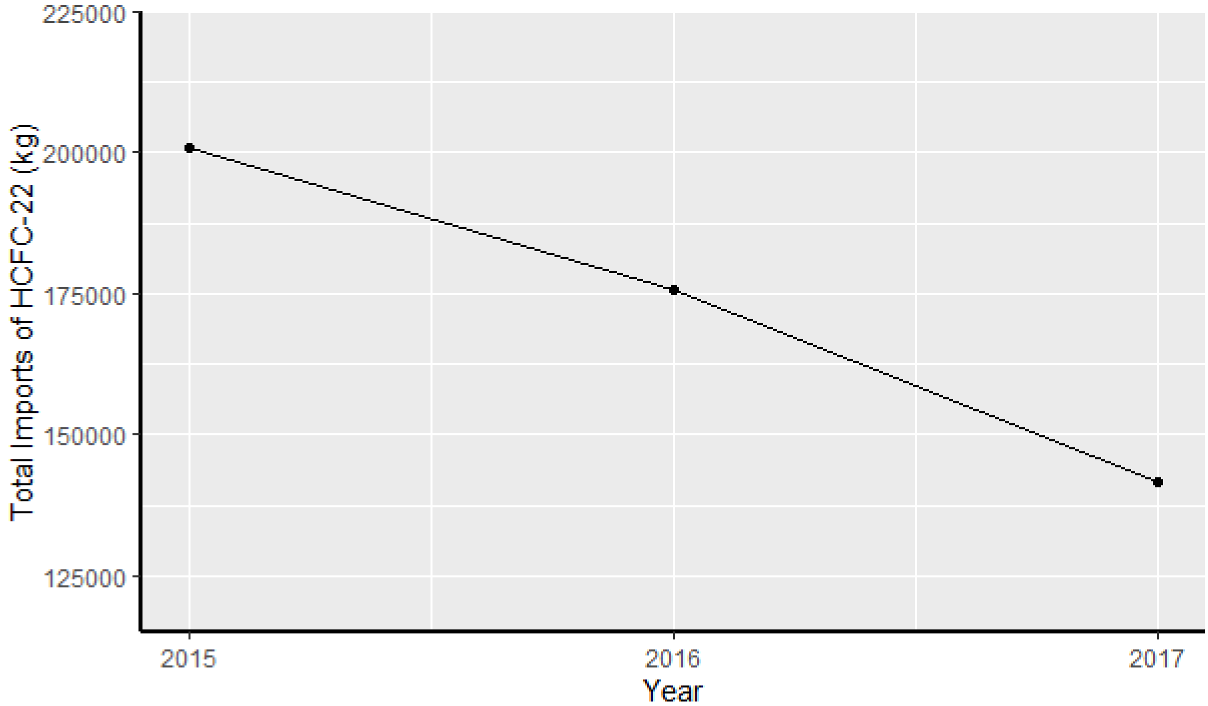


Figure 6.2: Total yearly imports of HCFC-22 by importers from 2015 to 2017

The results displayed in Figure 6.2 confirm that overall imports of HCFC-22 declined over the period 2015–2017, although the data values are slightly different from the data provided by the DMS over the same period. The percentage import decrease from 2015 to 2016 was 12.5% and 19.4% from 2016 to 2017. The overall percentage decrease from 2015 to 2017 was 31.9%. These results indicate a positive stepwise reduction in HCFC-22 consumption.

6.3 Consumption trends of HCFC-22 by individual companies

Based on data provided by the DMS and importers, the overall consumption of HCFC-22 is declining. However, there was a need to find out the consumption trends of specific individual companies in order to ascertain whether all companies in the industry were making efforts to reduce the consumption of HCFC-22. To obtain insights into individual companies, line graphs of the individual companies' consumption levels were plotted using quarterly consumption data covering the period 2015–2017 (Figure 6.4). As discussed earlier in section 6.2, this may be attributed to the influence of SA's licensing and quota restrictions, as SA remains the major supplier of HCFC-22 in Botswana.

As shown in Figure 6.3, there has been a steady decline in HCFC-22 consumption since 2007, from slightly below 3850 MT to about 2550 MT in 2016. During the same period, consumption of HFCs rose steadily from slightly below 1000 MT to about 3700 MT in 2016. Thus, the adoption of HCFC-22 alternatives has clearly reduced its consumption. The continued need for cooling and air conditioning, however, has meant that total consumption remained steadily on the rise.

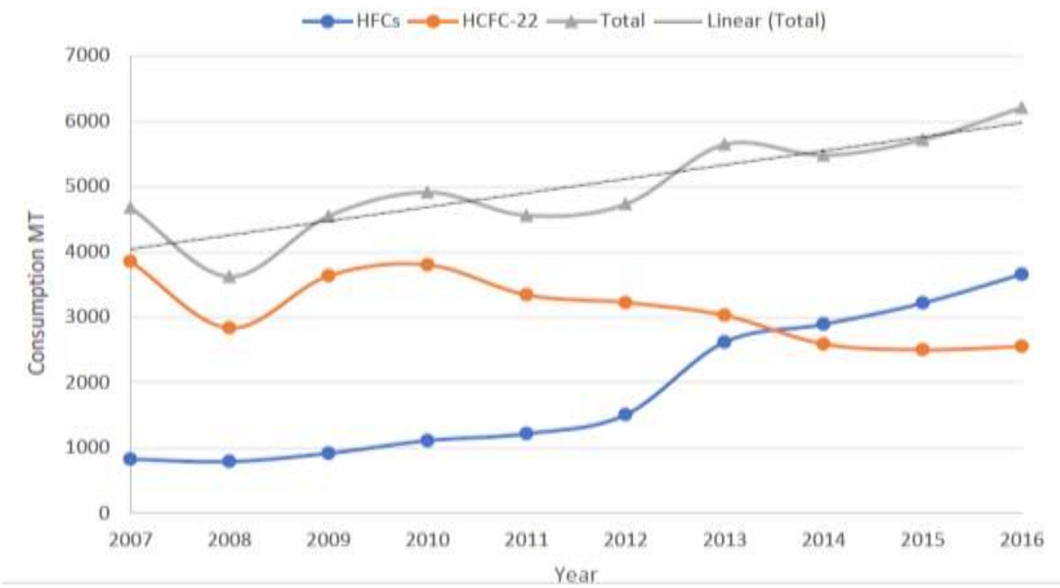


Figure 6.3: HCFC-22 and HFC consumption in South Africa. Source: UNIDO (2017)

In SA, the three biggest importers out of 19 account for approximately 90% of HCFC-22 imports. However, the consumption of HCFC-22 alternatives has seen a significant increase in interest in recent years as HCFC-22 is being phased out (UNIDO, 2017).

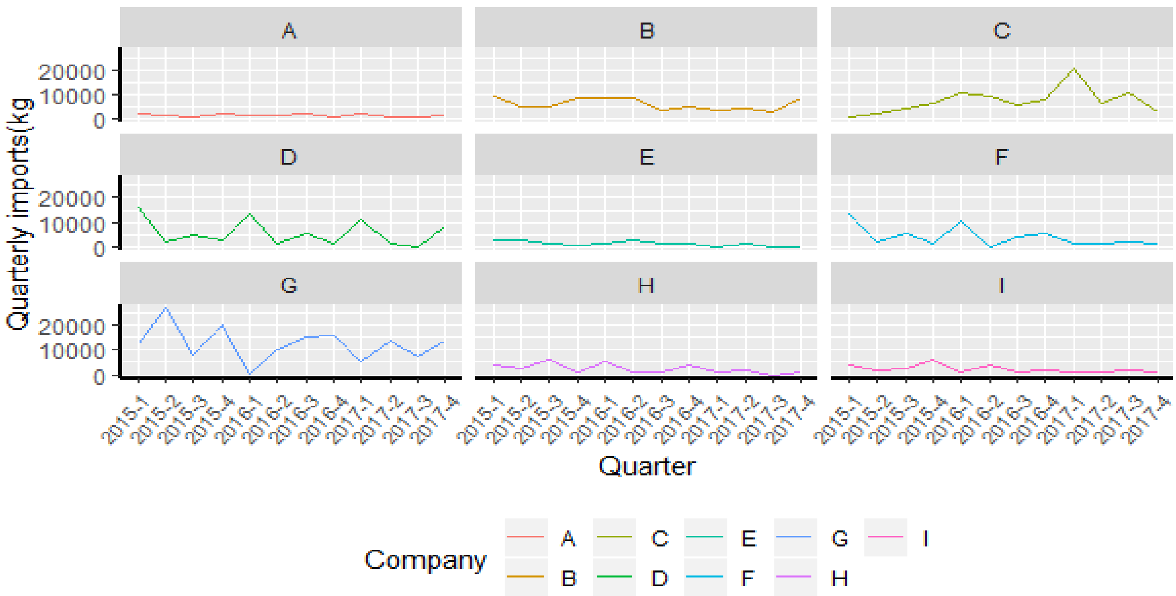


Figure 6.4: Quarterly imports of HCFC-22 by individual companies

Results displayed in Figure 6.4 show that most of the individual companies' consumption levels generally decreased during the 2015–2017 period, with only a few companies (companies B, D and G) with consumption levels that are not showing a clear downward trend. Hence, it would appear that most companies have been making efforts to reduce the consumption of HCFC-22, as articulated in Botswana's HPMP. At the same time, the World Bank (2018) notes that through its 2016 Stage II HCFC Phase-out Strategy and HCFC Production Phase-out Management Plan (HPPMP), there have been continued efforts by the Government of China to address the HCFC phase-out obligations in each of its major consumption sectors and the production sector.

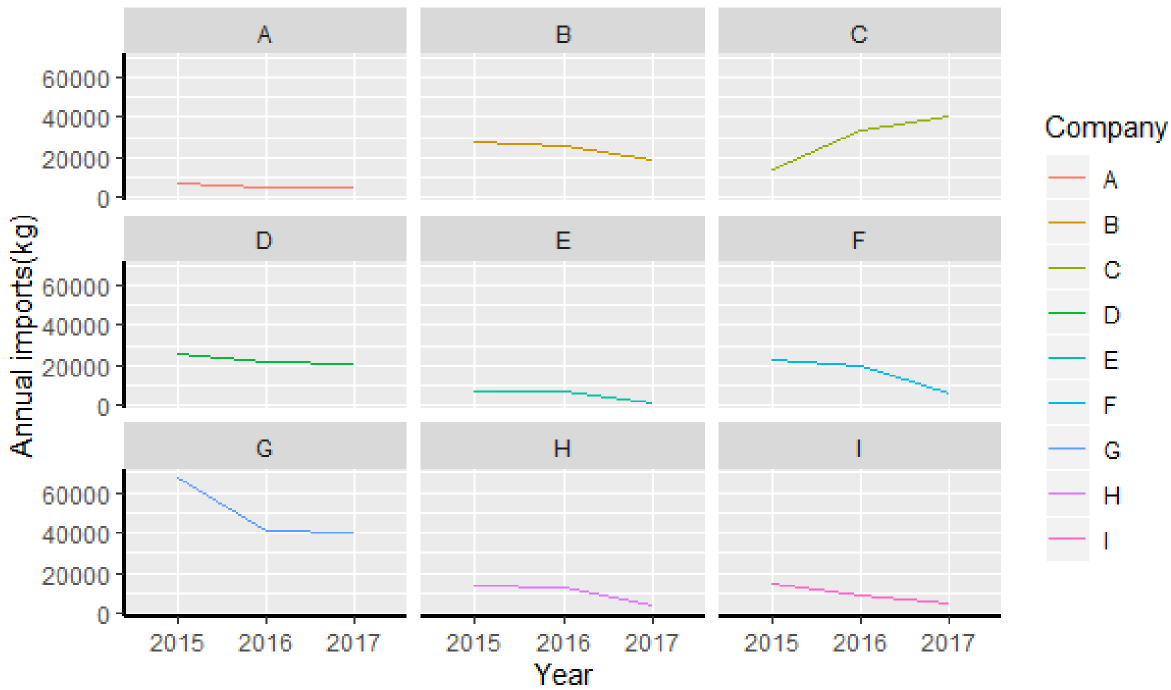


Figure 6.5: Annually imports of HCFC-22 by individual companies from 2015 to 2017

The annual imports of HCFC-22, as shown in Figure 6.5, also indicate a decline in consumption by most companies with the exception of Company C. Companies C and G show high consumption levels of HCFC-22. It turns out that Company C and G import the bulk (80%) of HCFC-22 from China, with only 20% coming from SA. China is not particularly stringent in regulating its exports to other countries. In terms of its specific line of business, Company C trades in new HCFC-22 units as well as HCFC-22 for servicing. Interview results also revealed that Company C offers the cheapest price on HCFC-22 units as compared to R410A. Company G had the highest consumption of 69 000 kg in 2015 which plummeted sharply to 42 000 kg in 2016 then maintained a plateaued consumption of close to 40 000 kg from 2016 to 2017.

Company A has the lowest and almost constant consumption of HCFC-22, while Company E similarly low consumption, which is declining and is close to zero consumption. Although Company F shows high HCFC-22 consumption in 2015, its rate of consumption is declining at a fast rate towards zero consumption. Therefore, the results in Figure 6.5 indicate that companies B, D, H and I are showing a decrease in HCFC-22 consumption.

6.4 An analysis of achievements of HCFC-22 phase-out milestones

Previous analysis (Figure 6.1) has revealed that consumption of HCFC-22 is generally declining. The next step, therefore, involved analysing whether the phase-out milestones were being achieved. A stair step diagram that compares actual consumption levels with the targeted phase-out consumption levels was used to analyse the achievement of milestones (Figure 6.6).

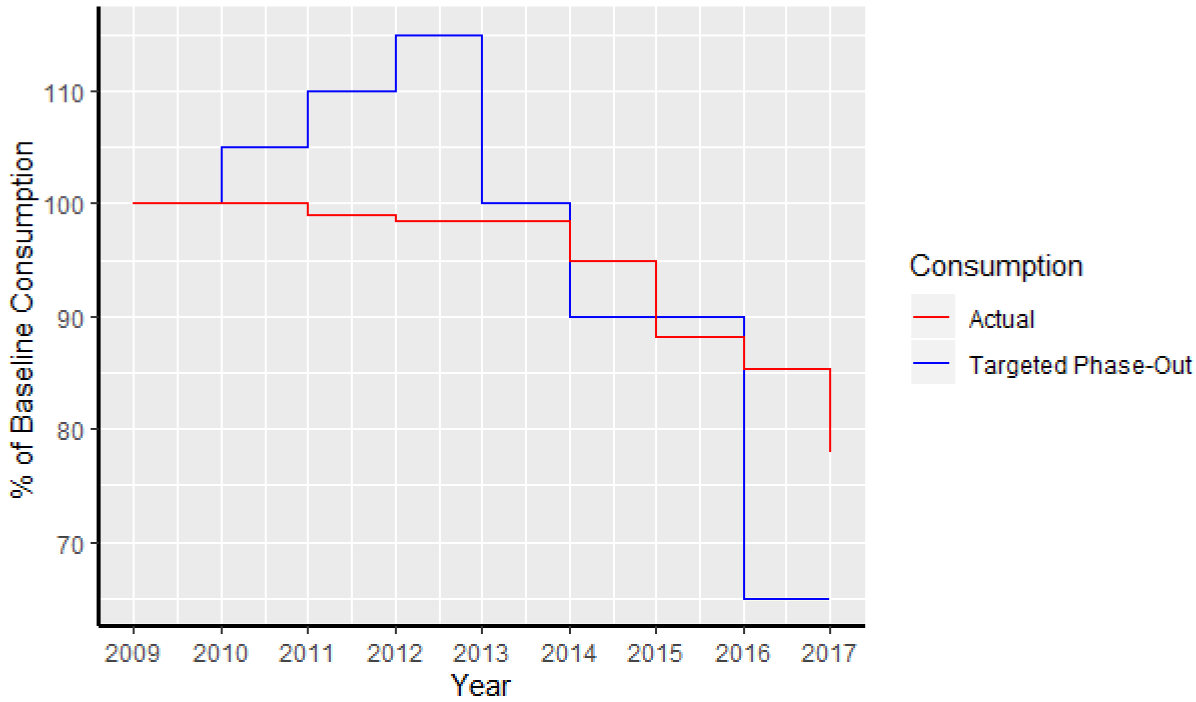


Figure 6.6: Actual consumption versus HCFC-22 targeted phase consumption as a percentage of baseline consumption

Figure 6.6 shows that actual consumption remained almost constant between 2009 and 2011. This was below the targeted consumption levels for the same period. According to the UNEP (2011a) report, HCFC-22 consumption was expected to rise by 5% of baseline consumption per year from 2010 up to 2012, before dropping down to freezing consumption in 2013 based on the country's economic development and the need for servicing RAC equipment. From 2012 to 2014, the actual consumption levels were at 98.5% of the baseline consumption, which represented a 2.5% drop in consumption. From 2014 to 2015, HCFC-22 consumption dropped from 95% to 88.2% of the baseline consumption, which was below the 90% target consumption. This represented an 11.8% drop in consumption, hence surpassing the 10% target. During this period, the targeted phase out was expected to be 90% of baseline consumption, which represented a 10% drop in consumption. This means that from 2012 to 2015, actual consumption was less than the targeted levels of consumption contained in the country's HPMP. During 2016 and 2017, there was a drop in HCFC-22 consumption to 85.3% and 78% of the baseline consumption respectively. This is still higher than 65% of base consumption of the 2020 target level. The 65% decrease must be achieved by 2020, meaning that 13% is still required from 2017 to 2020 consumption to achieve the target.

On the negative side however, in spite of these positive lag indicators, a number of lead indicators still need attention. These include, among others, the licensing system which still does not indicate the specific quotas allocated to individual companies, hence creating a loophole in border controls such as the shortage of gas identifiers at entry points. Poor information flows between the key stakeholders is also still a problem.

In regard to the milestones the DMS had achieved towards the phasing out of HCFC-22, the study results revealed the following:

- Capacity building had occurred to enable the country to meet its obligations under paragraph 1 of Article 5 to comply with the control measures set out in the MP.
- Pursuant to Article 7 on reporting of statistical data on the production, imports and exports of each of the controlled substances to the Secretariat (UNEP, 2018d), the country reported a decline in HCFC-22 consumption.
- Twenty-five per cent of refrigerant servicing technicians had been trained and certified by BRACA up to December 2017. The MP did not give quantified training targets for technicians; however, Botswana aimed to complete the training of technicians within the first stage (2016–2020). At the rate of 25% trained by 2017, and the same proportion annually thereafter, the country is set to have completed technician training by 2020.
- Thirty per cent of customs officers had received training on handling ODSs up to December 2017. The MP requirement/decision on research, development, public awareness and exchange of information (Article 9) required signatories to each develop a capacitation programme, including among other things workshops, demonstration projects, training courses, the exchange of expertise and the provision of consultants on control options, guided by the unique needs of each signatory, which were to be reviewed by the parties at their second meeting (UNEP, 2018d).

- Within two years of the entry into force of this Protocol and every two years thereafter, each Party shall submit to the Secretariat a summary of the activities it has conducted pursuant to Article 7. As at 2017, Botswana had remained compliant with this requirement, submitting to the Secretariat annual reports on its HPMP activities as well as its importation, consumption and emission milestones.
- One hundred per cent of HCFC-22 importers have been issued with import permits. This is in keeping with Article 4B, which deals with licensing. Pursuant to that article, each Party was to establish and implement an import and export licensing system for new, used, recycled and reclaimed controlled substances by 1 January 2000 or within three months of the date of entry into force of Article 4B, whichever came later.
- The MP required each Party, within three months of the date of introducing its licensing system, to report to the Secretariat on the establishment and operation of that system. Botswana reported the operation of its system in 2014, although the individual company quota system was not precisely in effect at the borders, with only industry-wide quotas applicable.
- Thirty refrigeration technician students are trained by the Gaborone Technical College annually. While the MP did not give each country-specific absolute milestone for the training of RAC technicians, Botswana's target was to have trained and certified 200 technicians in the first stage of the HPMP (2016–2020). Additionally, these RAC technicians were to undergo seven training workshops on good refrigeration practices, safety of hydrocarbons and promotion of low GWP alternatives, with seven three-day workshops for approximately 20 participants per workshop, scheduled during the first stage. So far, it is significant that all BRACA members were trained and given certificates of attendance in 2016, through a hands-on workshop comprising three days' theory and one day of practicals. All trainees were able to retrofit. BRACA registered about 250 formal refrigeration technicians in 2016.

6.5 Stakeholders' HCFC-22 phase-out initiatives

As part of the Botswana's HPMP, stakeholders are supposed to undertake various initiatives to ensure the effective phase-out of HCFC-22. The researcher asked the stakeholders about the various initiatives they are undertaking to ensure effective HCFC-22 phase-out. The initiatives are summarised in Table 6.1:

Table 6.1: Summary of stakeholders' initiatives for HCFC-22 phase-out

DMS	Customs	Companies
Formed BRACA in 2014 Carry out HCFC-22 phase-out awareness programmes Established ODS legislation in 2014 Facilitated the NOO national network Procured refrigerant identifiers Celebration of International Ozone Day annually	Monitoring of ODS imports Participate in BRACA meetings Attend information exchange workshops and conferences on ODS phase out	Raise awareness of HCFC-22 phase-out contractors and end users Encourage customers to buy HCFC-22 substitutes Participate in BRACA meetings

6.6 Challenges of HCFC-22 phase-out

Whilst some efforts have been made to meet the milestones as required under the MP, challenges still exist. The DMS indicated that it is still facing major challenges in implementing the phase out due to limited funding. Money is needed for the construction of ODS storage facilities for seized ODSs at entry ports and the NOU lacks ODS destruction facilities and storage facilities for seized ODS equipment. Another reason for tracking ODS phase-out is the disposal of ODS manufactured equipment. The disposed, confiscated and surplus ODSs must be stored, reused or destroyed in an environmentally friendly manner. The customs department also does not have adequate refrigerant identifiers to use at points of entry and the results indicate that 35% stated that they lack training on handling ODS. Letsholo (2019) pointed out that Botswana does not have warehouses to keep confiscated ODSs at entry points. This weakens the ODS control mechanism at entry ports and results in all the seized ODSs eventually finding their way into the country. There is no doubt that this slows down efforts to phase-out ODS sale and usage in the country. To promote the use of alternatives, the NOU is supposed to undertake awareness campaigns, but the DMS revealed that, as a result of inadequate funds, the NOU has been unable to undertake awareness programmes to any real extent. The other challenge indicated by the DMS officials has been the government red tape, as a result of which plans take a long time to be implemented. The other challenge highlighted by the DMS is the lack of policy or regulatory measures to promote ODS alternatives, resulting in high demand for HCFC-22. The study results indicate that about 78% of importers confirmed that because it is cheap, consumers prefer HCFC-22 even though it is not environmentally friendly compared to its alternatives. As indicated in section 6.7.1.2 below, for the period 2009–2017, the total estimated costs of servicing replaced units using HCFC-22 were P169 862.48, whereas those for servicing units using R410A were P351 167.49. Thus, HCFC-22-based equipment cost P181 305.01 less to service than R410A-based equipment over the same period.

An additional challenge highlighted by participant stakeholders was the price of HCFC-22 alternatives which are still high compared to HCFC-22, leading to technicians and customers resorting to HCFC-22. When asked about the challenges of phasing out HCFC-22, about 67% of importers' responses highlighted that they did not have money to invest in HCFC-22 substitutes and new technologies. The DMS also highlighted that importers were reluctant to renew the import permits when they expired. One of the reasons for this reluctance is the fact that import licences are not functional at Botswana entry points, which means firstly that companies can import more than their quotas, and secondly, that the NOU's assumed importer numbers are understated. As a result, there is an increased chance of illegal trading in HCFC-22, which keeps HCFC-22 consumption higher than desired.

About 67% of importers' responses highlighted that not all technicians are familiar with servicing alternatives and lacked technical expertise. This likely had the effect of increasing emissions during refrigerant charge and transfer. It is also noteworthy that the alternative technologies, if not properly handled, may pose safety and health problems. On the positive side, proper handling of alternative technologies obviously reduces the demand for HCFCs, which in turn reduces GHG emissions and boosts climate change mitigation efforts. An additional spinoff is the reduction of CO_2 emissions at a national level and increased energy efficiency in RAC equipment. The latter ultimately reduces energy consumption and electricity costs (UNEP, 2015f). About 55% of the importers' responses stressed that some customers do not understand the phase-out, as they still demand HCFC-22, which some importers sold very cheaply, resulting in some government departments still buying a lot of HCFC-22 units imported from China. About 88% of interview responses from importers confirmed that HCFC-22 imported from China is cheaper than that from SA and thus consumers prefer the Chinese product.

The UNEP (2018c) notes that there are common challenges that Article 5 signatories face in phasing out HCFC-22. The first, according to the UNEP (2017a), stems from difficulties faced in trying to raise awareness emanating from the many different target audiences and messages that must be addressed, thus requiring the split of not only resources but also messages. The second challenge is cost-related. For starters, the cost of HCFC-22 is 30% of that of high GWP HFCs, which means alternative technology remains very expensive. In fact, it is hardly surprising that these challenges exist in some Article 5 countries, including Botswana, which get some of their HCFC-22 from China. China itself still manufactures and consumes large amounts of HCFC, while Asian and Pacific countries still face border control enforcement challenges and loopholes in their licensing and quota systems (UN Environment, 2019).

6.7 **Impacts of HCFC-22 phase-out in Botswana**

The adverse impacts of stratospheric ozone depletion on human welfare and the environment are of major concern (Norval *et al.,* 2011; Derco *et al.,* 2018). In this regard, the economic, social and environmental impacts of phasing out HCFC-22 were evaluated and the results are presented here.

6.7.1 Economic impact of HCFC-22 phase-out

6.7.1.1 *Impact of reduced consumption of HCFC-22*

The implementation of the HCFC-22 phase-out seeks to reduce consumption of HCFC-22 and it is expected that consumers will purchase less HCFC-22 refrigerant if they shift to substitutes. A comparison of HCFC-22 consumption under constrained and unconstrained conditions provides information on the impact of the phase-out on consumption. The full details of calculations of HCFC-22 consumption under constrained and unconstrained conditions are described in Chapter 3 section 3.5.1.2. Equations 3.3 and 3.4 presented in section 3.5.1.2 were used to compute the results presented in Table 6.2.

Table 6.2: Constrained and unconstrained HCFC-22 consumptions in Botswana

Year	Consumption (kg)			Cumulative difference (kg)
	Constrained	Unconstrained	Difference	
2009	200 000	0	0	0
2010	200 000	200 000	0	0
2011	198 000	220 500	22 500	22 500
2012	197 000	231 500	34 500	57 000
2013	197 000	243 100	46 100	103 100
2014	190 000	255 300	65 300	168 400
2015	176 300	268 000	91 700	260 100
2016	170 600	281 400	110 800	370 900
2017	156 000	295 500	139 500	510 400

As shown in Table 6.2, phasing out HCFC-22 has resulted in the country consuming smaller quantities of HCFC-22 than it would if there were no phase out. By constraining the HCFC-22 consumed, the country saved 22 500 kg of potential HCFC-22 in 2011. This figure increased to 139 500 kg of potential HCFC-22 consumption saved in 2017. The cumulative quantity of potential HCFC-22 consumption saved was estimated to be 510 400 kg by 2017. These HCFC-22 substances could have been emitted to the environment and caused depletion of the ozone layer. For roughly the same period, China, one of the most important suppliers of HCFC-22 and related equipment, intends to reduce consumption of HCFC-22 residential air-conditioners from 38.16 million units in 2013 to 0 in 2030, with HCFC-22 consumption (for servicing purposes only) correspondingly expected to decrease from 65 875 t in 2013 to 5082 t in 2030 (Wan *et al.*, 2011).

6.7.1.2 *Impact of phasing out HCFC-22 on servicing costs and income*

Servicing costs of HCFC-22 equipment depend on the servicing requirements of the refrigerant (determined by the leakage rate and the quantity of equipment units) and the cost of the refrigerant. To evaluate the effect of the HCFC-22 phase-out on servicing costs, the servicing costs of newer R410A units are compared with the servicing costs that could have been incurred if the same units had been replaced with HCFC-22 type equipment units. As noted by the UNEP (2017c), in Namibia there is a general decrease in the prices of substitute refrigerants, whilst the price of HCFC-22 has generally been increasing. To estimate servicing requirements assuming HCFC-22 and R410A refrigerants were used for the replaced units, the following assumptions were made (UNIDO, 2015; UNEP, 2018a):

- Disposed units are replaced with units that use R410A.
- The leakage rate for HCFC-22 is 7% whilst that for R410A is 5%.

- The charge rate is 6.3/unit/kg for HCFC-22 and R410A.
- The average refilling cost for HCFC-22 is P2.46 and for R410A it is P7.12.

The full details of calculations of the comparison of the economic impacts of servicing costs of HCFC-22 and R410 from 2009 to 2017 are described in Chapter 3, section 3.5.1.2. Equation 3.5 presented in Section 3.5.1.2 was used to determine servicing requirements for HCFC-22 and R410A equipment in each year and the results are presented in Table 6.3. Equation 3.6 was then used to compute the average servicing costs of HCFC-22 and R410A for the period 2009–2017. The results are presented in Table 6.3.

Table 6.3: Comparison of HCFC-22 and R410A servicing costs from 2009-2017

Year	Replaced units	Servicing requirements per kg	
		HCFC-22	R410A
2009	0.00	0.00	0.00
2010	0.00	0.00	0.00
2011	85 653.50	37 773.19	26 980.85
2012	1 688.62	744.68	531.91
2013	0.00	0.00	0.00
2014	11 820.33	5 212.77	3 723.40
2015	23 134.08	10 202.13	7 287.23
2016	9 625.13	4 244.68	3 031.91
2017	24 653.83	10 872.34	7 765.96
Total	**156 575.48**	**69 049.79**	**49 321.28**
Average refilling cost per kg		P2.46	P7.12
Total refilling cost (Pula)		**169 862.48**	**351 167.49**

Table 6.3 shows that the total estimated cost of servicing replaced units using HCFC-22 is P169 862.48. This is lower than the estimated cost of servicing using replaced units that use R410A, which is P351 167.49. This means that the incremental cost of servicing newer equipment that uses R410A is about P181 305.01. There is thus a negative gain in servicing costs emanating from the use of R410A-based air conditioners. In fact, Wan *et al.* (2011) noted that R410A is two to three times more expensive than HCFC-22 owing to patent protection, and so is the cost of machine maintenance.

6.7.1.3 *The impact of the HCFC-22 phase-out on energy costs*

The phase out of HCFC-22 equipment saves energy because HCFC-22 substitutes are more energy-efficient (UNEP, 2018b). To estimate the impact of the phase-out of HCFC-22 on energy costs, the researcher assumed that disposed units that use HCFC-22 were replaced with units that use R410A. According to the UNEP (2018b), equipment with R410A refrigerant uses 30% less electricity compared to HCFC-22 reliant equipment, which is equivalent to electricity savings of 68 kWh/month and 816 kWh per year per unit. Electricity consumption per unit is assumed to be 228 kWh per month and, on average, electricity costs about P1.07 per kWh for consumption above 200 kWh (UNEP, 2018a). Equation 3.7 described in Section 3.5.1.2 was used to compute energy savings per year and the results are presented in Table 6.4. The total energy savings in monetary value for the period 2009–2017 was further calculated using the Equation 3.8 and the results are presented in Table 6.4.

Table 6.4: Estimated energy savings of phasing out HCFC-22 from 2009-2017

Year	Replaced units	Energy savings (kWh)
2009	0.00	0.00
2010	0.00	0.00
2011	85 653.50	69 893 252.28
2012	1 688.62	1 377 912.87
2013	0.00	0.00
2014	11 820.33	9 645 390.07
2015	23 134.08	18 877 406.28
2016	9 625.13	7 854 103.34
2017	24 653.83	20 117 527.86
Total	**156 575.48**	**127 765 592.71**
Average cost/kWh		P1.07
Total energy savings (Pula)		**135 431 528.30**

Table 6.4 shows that for the period 2009–2017, Botswana saved almost 128 million kWh of electricity. At an average cost of P1.07, the savings amounted to P135.4 million. These are significant savings for households and companies compared to the higher energy bills resulting from the use of HCFC-22 refrigerant. According to Chaturvedi and Sharma (2014), research in India by the Council on Energy, Environment and Water (CEEW) found out that a switch to usage of lower GWP units with energy improvements could contribute to a 15% energy saving for a business set up and a reduction of 31 to 38% in residential houses.

Similar trends have been observed or projected in Ghana, Saudi Arabia, SA and China. The UNEP (2017a) reports that Ghana, in conjunction with the Global Environment Facility (GEF), embarked on a project to achieve energy efficiency in the domestic refrigeration and air-conditioning sector. Similar initiatives were also underway after 2016 in Saudi Arabia in the context of new technology promotion and building regulations. By the same token, SA recognises that while the installation of RAC equipment costs slightly more, in the long run it will lead to energy savings (DEA, 2016). For China, Wan *et al* (2011) projected the energy savings using R410 to increase rapidly along with the phase-out schedule, and to be higher than those from HCFC-22 at 3.8×10^{11} kWh for the 2013–2030 period.

6.7.1.4 *Stakeholders' perception of the economic impact of HCFC-22 phase-out*

The stakeholders were asked about their perceptions of the economic impact of HCFC-22 phase-out using the Likert scale-type questions. The results are shown in Figure 6.7.

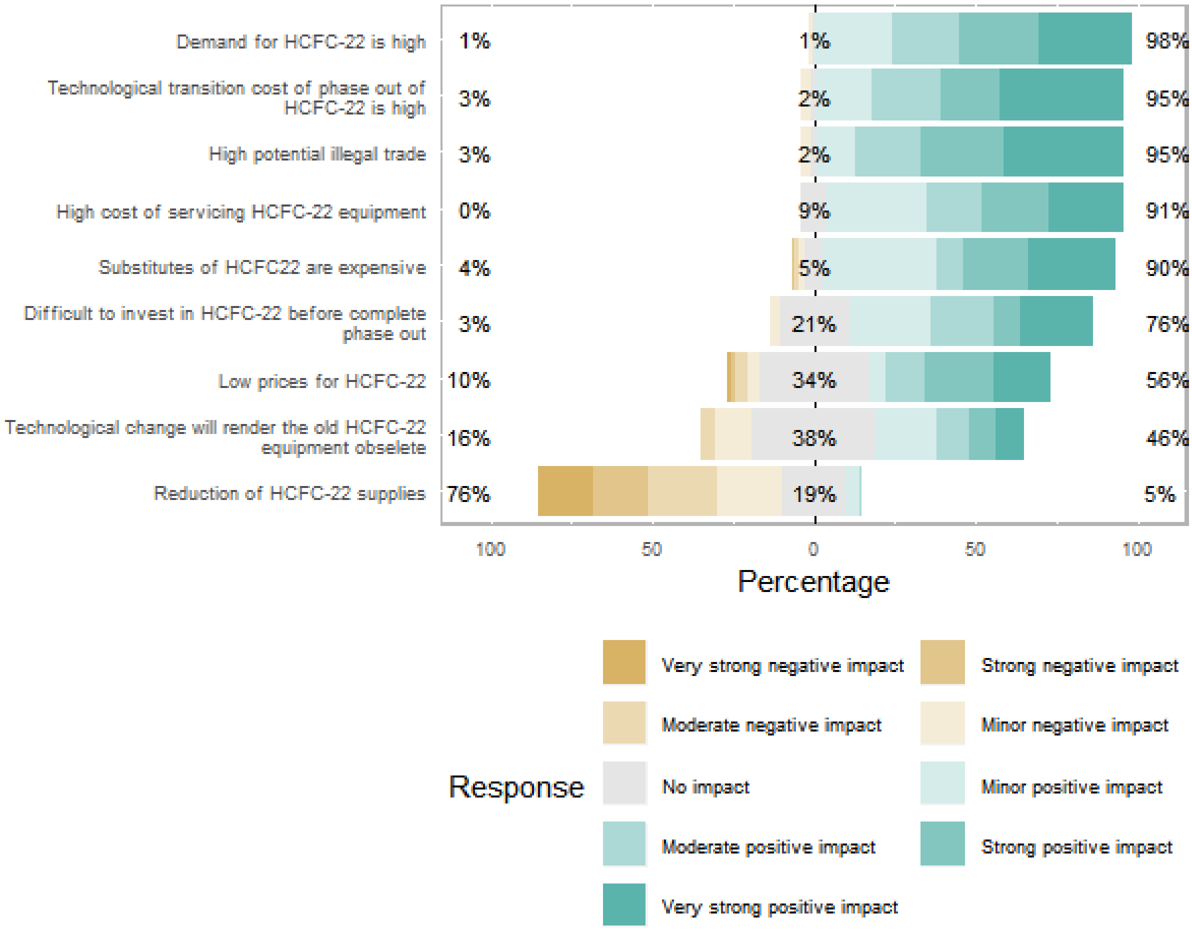


Figure 6.7: Stakeholders' perception of the economic impact of HCFC-22 phase-out

Most stakeholder participants indicated that the HCFC-22 phase-out has had a negative impact, resulting in high demand for HCFC-22 (98%) and high potential for illegal trading (95%). Whilst most participants noted that the consumption for HCFC-22 had decreased, 46% indicated that HCFC-22 phase-out had increased the replacement cost of equipment as the cost of importing HCFC-22-compliant equipment and technological transfer costs were high. It had also increased the cost of servicing as the prices of substitutes are very high. On a positive note, stakeholders (78%), indicated that supplies of HCFC-22 equipment had decreased. About 67% of companies indicated that since the phase-out of HCFC-22 had commenced, sales of HCFC-22 had decreased.

When asked about the price trend of HCFC-22 since the phase-out started, companies and consumers, 44% and 48% respectively, indicated that the prices were decreasing. About 33% of companies and 18% of consumers were also of the view that prices were increasing, with 11% and 23% of companies and consumers respectively holding the view that the prices were stagnant. Roughly 11% of companies and 7% of consumers saw prices fluctuating (Figure 6.8).

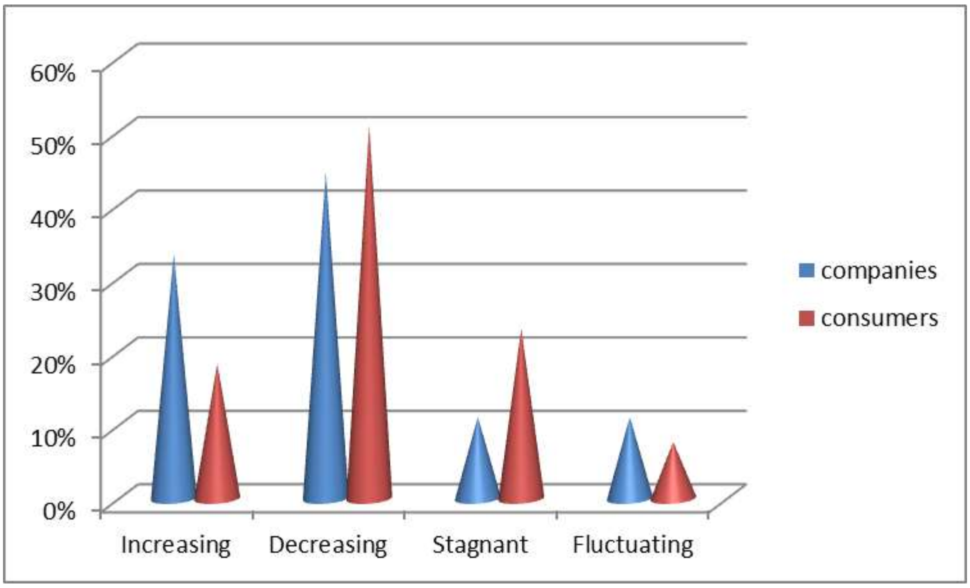


Figure 6.8: Stakeholders' perception of the price trend of HCFC-22 equipment since the phase-out started

The UNEP (2017c) reported that at the time the domestic price of HCFC-22 in Namibia was significantly high at US$13.38 per kg and only a small number of registered importers brought in HCFC-22. This was meant to reduce the demand for HCFC-22. The report further indicated that the importation of ODS alternatives including R410A was increasing. As a result of HCFC-22 phase-out, McLaughlin (2018) also reported an over 50% increase in the price of HCFC-22 refrigerant in China since September 2017.

6.7.2 The environmental impacts of HCFC-22 phase-out

6.7.2.1 *The impact of the HCFC-22 phase-out on ozone depletion potential (ODP)*

Phase out of HCFC-22 reduces the emission of gases that can harm the ozone layer (Wan *et al.*, 2011). Small quantities of HCFC-22 equipment units translate into lower amounts of the HCFC-22 that can be leaked into the stratosphere and deplete the ozone layer. The extent to which a certain quantity of HCFC-22 can deplete the ozone layers is measured by the ODP. The ODP of HCFC-22 is 0.055 per kilogram (as discussed in the literature review, section 2.8.2). The consumption levels under constrained and unconstrained conditions were used to determine the ODP from 2010 to 2017. Equation 3.9 in section 3.5.1.3 was used to estimate the ODP of HCFC-22 under both constrained conditions and unconstrained conditions, as shown in Table 6.5. Equation 3.10 was further used to compute the cumulative difference in ODP under both these conditions. The ODP savings are summed up cumulatively to find out the total ODP savings per each year from 2009 to 2017. The details of the calculations are presented in section 3.5.1.3.

Table 6.5: Estimated ODP of HCFC-22 under constrained and unconstrained conditions

Year	ODP		Difference	Cumulative difference
	Constrained	Unconstrained		
2010	11 000.0	11 000	0	0
2011	10 890,0	12 127.5	1 237.5	1 237.5
2012	10 835.0	12 732.5	1 897.5	3 135.0
2013	10 835.0	13 370.5	2 535.5	5 670.5
2014	10 450.0	14 041.5	3 591.5	9 262.0
2015	9 696.5	14 740.0	5 043.5	14 305.5
2016	9 383.0	15 477.0	6 094.0	20 399.5
2017	8 580.0	16 252.5	7 672.5	28 072.0

Table 6.5 shows that the ODP of HCFC-22 in the country decreased from 11 000 in 2010 to 8580 in 2017 under constrained conditions, representing a decrease of 22%. If the country had not implemented the phase-out of HCFC-22, the ODP under unconstrained conditions would have increased from 11 000 to 16 252.5, representing an increase of 47.8%. This shows that if there were no phase-out of HCFC-22, the ODP would have increased significantly. The cumulative effect of implementing phase-out from 2010 to 2017 is 28 072 ODP. In other words, implementing the phase-out has saved the country from harmful emissions amounting to 28 072 ODP. This shows that the phase-out has had a significant impact on reducing the ODP of HCFCs in Botswana. Elsewhere, similar positive developments have been noted.

Specifically, the UNEP (2017a) hailed the declining consumption trends in Bahrain, Bosnia and Herzegovina, Brazil, Burkina Faso, Chile, Ghana, Kuwait, the former Yugoslav Republic of Macedonia, Mexico, Nigeria, Saudi Arabia and Serbia. Only 2.8% of the countries in that study were found to be non-compliant, with the bulk reporting consumptions well below the MP limits. The net savings achieved as a result amounted in absolute terms to 4342 ODP tonnes of HCFC consumption in 2013 and 4780 ODP tonnes of HCFC consumption in 2015.

6.7.2.2 *The impact of the HCFC-22 phase-out on global warming potential*

HCFC-22 also emits GHGs that have climate change effects and cause global warming (Zhao *et al.*, 2015). Therefore, reducing the emission of HCFC-22 has the effect of reducing overall GWP. The global warming effect of gases is measured by the GWP. HCFC-22 has a GWP of 1780 per kilogram (as discussed in the literature, section 2.7.2). To evaluate the effect of reducing HCFC-22 on global warming, a comparison of the GWP of the gas under constrained and unconstrained conditions was undertaken. Hence, the effect of HCFC-22 on GWP was analysed under these conditions. The subsequent differences and cumulative differences of GWP for each year from 2009 to 2017 were computed using Equation 3.11, as explained in section 3.5.1.3, and the results are presented in Table 6.6.

Table 6.6: Estimates of GWP of HCFC-22 under constrained and unconstrained conditions

Year	GWP		Difference	Cumulative difference
	Constrained	Unconstrained		
2010	356 000 000	356 000 000	0	0
2011	352 440 000	392 490 000	40 050 000	40 050 000
2012	350 660 000	412 070 000	61 410 000	101 460 000
2013	350 660 000	432 718 000	82 058 000	183 518 000
2014	338 200 000	454 434 000	116 234 000	299 752 000
2015	313 814 000	477 040 000	163 226 000	462 978 000
2016	303 668 000	500 892 000	197 224 000	660 202 000
2017	277 680 000	525 990 000	248 310 000	908 512 000

Table 6.6 shows that, like the ODP, the GWP also decreased by 22% from 2010 to 2017. If the phase-out had not been undertaken, the GWP would have also increased by 47% for the same period. Cumulatively, 908 512 000 GWP has been saved by implementing the phase-out of HCFC-22. This shows that implementing the phase-out has not only significantly decreased the ODP but also the GWP. This means that the consumption of 28 072 ODP of HCFC-22 if emitted into the atmosphere, could have contributed to an equivalent of 908 512 000 tonnes of carbon dioxide equivalent (CO_2-eq). This level of HCFC-22 CO_2-eq emission could have

considerable effects on climate change. The complete phase-out of HCFC-22 as a GHG will therefore have climate benefits of carbon savings which have implications to climate change.

Comparatively, according to the UNEP (2019a), China was on course with its HCFC freeze targets in 2013 and in 2015, phasing out 71 000 MT of HCFC-22 production and 45 000 MT of HCFC-22 consumption, on the back of the closure of 88 000 MT production capacities. Additionally, in order to directly influence climate change mitigation efforts, 76% of the HCFC phase-out projects switched over to low GWP alternatives (*ibid*.). The expectation, based on these trends, was that eventually the cumulative emission reduction of HCFC-22 would be equivalent to 12 to 15 gigatons of CO2e worldwide (World Bank, 2018). Knutson *et al.* (2015) similarly hails the Costa Rican people's considerable efforts to reduce their environmental impact for the sake of their economy, their countrymen and the global community, and in particular their commitment to become carbon neutral by 2021. They note, however, that Costa Rica still has a long way to go before the ultimate phase out of HCFCs is realised.

6.7.2.3 *Ozone depleting potential saved by replacing HCFC-22 units*

In this study it is assumed that when users dispose old units with HCFC-22 refrigerant, they replace them with units that use substitute refrigerant (R410A) with zero ODP. In other words, the replaced units with R410A do not emit gases that harm the ozone layer but they do have an impact on global warming (Bolaji, 2012; Migneco and Farrugia, 2019). The ODP saved is the amount of ODP that could have been emitted had the units been replaced with units that use HCFC-22. The ODP saved was calculated by determining the ODP that would have been obtained each year if disposed HCFC-22 units had been replaced by the same HCFC-22 alternative equipment. The ODP saved was computed for each year and the cumulative ODP from 2009 to 2017 using Equation 3.12. Table 6.7 shows an estimation of the ODP saved.

Table 6.7: Estimate of ODP saved by replacing HCFC-22 units

Year	Replaced Units	ODP HCFC-22	ODP Cumulative
2010	0	0	0
2011	85 653	4710.915	4 710.915
2012	1 689	92.895	4 803.810
2013	0	0	4 803.810
2014	11 820	650.1	5 453.910
2015	23 134	1272.370	6 726.280
2016	9 625	529.375	7 255.655
2017	24 654	1355.970	8 611.625
Total	**156 575**	**8611.625**	

Table 6.7 shows that a total of 156 575 units is estimated to have replaced old units of HCFC-22 disposed units from 2010 to 2017. The units replaced are assumed to be using substitute refrigerants with zero ODP. If the units had been replaced using units that use HCFC-22, ODP would have accumulated from 4710.915 in 2011 to 8611.625 in 2017. In other words, by replacing HCFC-22 units with substitute units that have zero ODP, potential emissions with an ODP of 8611.625 would have been prevented from harming the ozone layer. Elsewhere, in India, according to government's Ozone Layer Protection, projected phase-out figures of ODP after successful HPMP implementation amounted to 769.49 tons (Government of India, 2017).

6.7.2.4 *The global warming potential of disposing of HCFC-22 units*

Whilst replacing old units with new units that use refrigerant substitutes with zero ODP helps to protect the ozone layer, it is not the same with global warming. In this study it is assumed that the new replacement units use R410A which has a higher GWP than HCFC- 22. The GWP for HCFC-22 and R410A are 1780 and 2088 respectively (Chen, 2008; Li *et al.*, 2016). The incremental GWP of replacing an older HCFC-22 unit with an R410A unit is therefore 308 GWP. Table 6.8 shows the estimated incremental GWP effect resulting from replacing old units with R410A units.

Equation 3.13 was used to determine the incremental environmental cost of replacing HCFC-22 units with R410A units, as explained in section 3.5.1.3. The incremental GWP of using R410A units instead of HCFC-22 units and the resulting cumulative incremental GWP were computed for each year for the period 2009–2017 and the results are presented in Table 6.8.

Table 6.8: Estimate of GWP of replacing HCFC-22 units

Year	Replaced units	Incremental GWP	Cumulative GWP
2010	0	0	26 381 124
2011	85 653	26 381 124	26 901 336
2012	1 689	520 212	26 901 336
2013	0	0	30 541 896
2014	11 820	3 640 560	37 667 168
2015	23 134	7 125 272	40 631 668
2016	9 625	2 964 500	48 225 100
2017	24 654	7 593 432	26 381 124
Total	**156 575**	**48 225 100**	

Based on the quantity of replacement units, the incremental GWP of replacing HCFC-22 old units with new R410A units has been gradually increasing over the years. This replacement results in a total cumulative increase in GWP of 48 225 100 in 2017 from 26 381 124 in 2011 (Table 6.8). This shows that the replacing of old units with newer units that use R410A may have a significant negative effect on global warming. As a result, the use of R410A as a substitute for HCFC-22 has a negative effect on the climate. However, Shah *et al.* (2019) forecast a positive future picture based on two scenarios (*ibid*.) worldwide, shifting from HCFs with high GWP to "economic" energy efficiency levels and low-GWP refrigerants by 2050, helping to avoid up to 240.1 GT CO_2e and switching over to "best-available technology" energy efficiency levels and low GWP refrigerants by 2050 avoiding up to 373 GT CO_2e with existing electricity grid emission factors. They attribute close to two-thirds of the projected cumulative savings to reduced electricity sector emissions from improved energy efficiency. Shah *et al.* (2019) conclude that pursuing high energy efficiency in concert with the transition to lower GWP refrigerants to achieve maximal GHG reductions with the least amount of equipment redesign and replacement would be highly beneficial. In Botswana, UNEP, (2018f) reported that the use of hydrocarbon (HC) refrigerants is currently limited to a small set of equipment which includes small supermarket and domestic fridges. There are no safety standards on the use and servicing of flammable refrigerants; technicians are guided by relevant international safety guidelines. However, the NOU has initiated a dialogue with the Botswana Bureau of Standards (BOBS) for the development of such a standard.

6.7.2.5 *Stakeholder perceptions of the environmental impacts of phasing out HCFC-22*

Stakeholder participants were also asked to provide their perceptions of the environmental impact of HCFC-22 phase-out. Likert scale-type questions were used to determine the environmental impact and the results are summarised and presented in a Likert plot displayed in Figure 6.9.

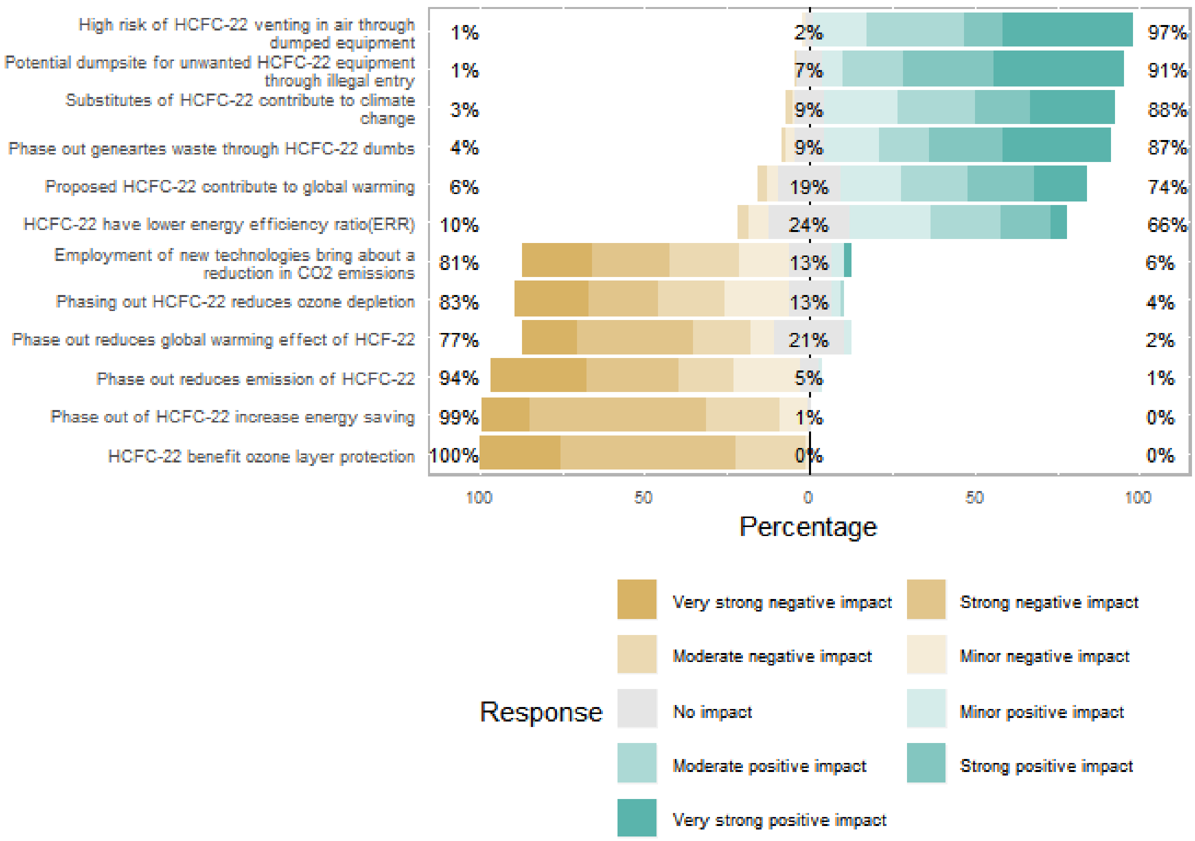


Figure 6.9: Stakeholder perceptions of the environmental impacts of phasing out HCFC-22

Most stakeholder participants were of the view that phase-out of HCFC-22 had a positive impact on the environment. They indicated that it reduces HCFC-22 emissions (94%), thereby reducing ozone depletion (83%) and global warming effects (81%). They further indicated that phase out HCFC-22 has a lower energy efficiency rating and therefore use of substitutes increases energy savings (99%). However, most stakeholders (97%) were concerned that phase-out of HCFC-22 generates waste through dumpsites and some of the HCFC-22 may leak out from the dumped equipment (91%). They were also concerned that substitutes for HCFC-22 contribute to global warming (88%).

When asked if they carry out leakage tests on HCFC-22 equipment before selling them, 89% of companies indicated that they do not test for leakage. Observation results also indicated that only one (11%) company had a leak detector. There is a possibility of uncounted HCFC-22 leaks into the environment. Fortunately, the picture is positive elsewhere, for example in China, Li *et al.* (2019) observed that recently there have been decreases in atmospheric growth rates for the HCFC-22, following the imposed bans on production and consumption. Conclusively though, they noted that it is relatively complex to analyse the overall environmental impact of HCFC phase-out decisions, hence there can be no universal solution for all situations.

6.7.3 Social impacts of HCFC-22 phase-out

This section evaluates the stakeholders' perceptions on the social impacts of HCFC-22 phase-out. The social impacts of the HCFC-22 phase-out were analysed using the opinions of the stakeholders, who were asked to rate the social impact of HCFC-22 phase-out. The questions were Likert scaled, ranging from strong positive impact to strong negative impact. The findings were summarised on a Likert plot to gauge the general social impact of HCFC-22 phase-out. The results are presented in Figure 6.10.

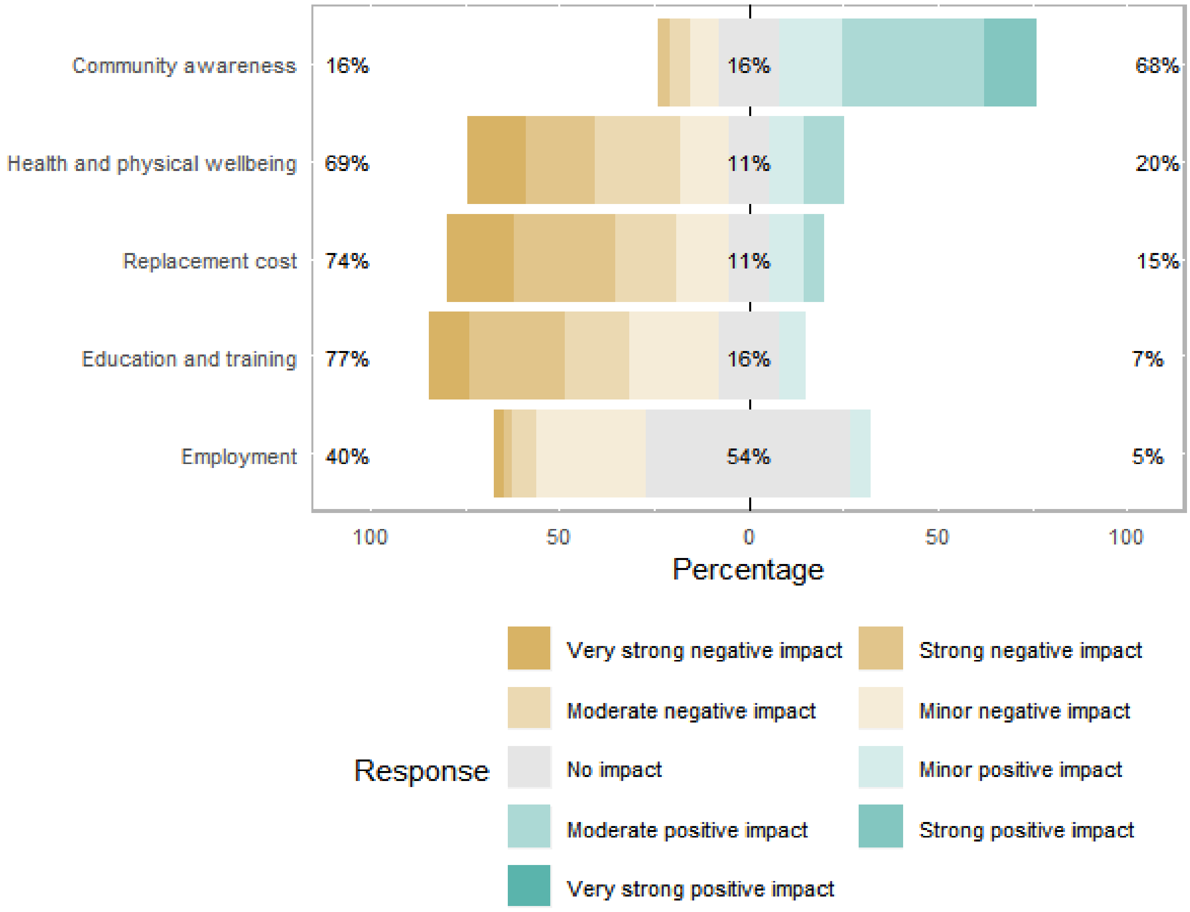


Figure 6.10: Stakeholder perceptions of the social impacts of phasing out HCFC-22

The majority of participating stakeholders were of the opinion that HCFC-22 phase-out has positive social benefits. About 79% mentioned positive social impacts on people's health and wellbeing. Stakeholders were also of the opinion that phasing out HCFC-22 has a positive social impact on community awareness (69%). This might be a result of public awareness campaigns carried out by the NOU and BRACA. Stakeholders also perceived that phasing out HCFC-22 has had no social impact on employment (54%). As discussed in the literature review, Botswana does not manufacture HCFC-22; the refrigerant is imported for servicing the existing equipment. Therefore, there is minimal impact associated with job loss. HCFC-22 phase-out has had positive social impacts on education and training, according to 77% of respondents. As presented in section 5.6, customs officers and those in the servicing sector are being trained to handle and service ODSs and ODS equipment. Figure 6.10 shows the negative impacts on the replacement cost of HCFC-22. This has a negative effect on socioeconomic benefits because the costs of HCFC-22 substitutes are high.

6.8 **Conclusion**

Undoubtedly, the results of this study point to an auspicious picture of Botswana having thus far achieved significant economic, social and environmental effects as a consequence of the implementation of its HPMP. There remain a few challenges and paradoxes worth pointing out and pondering, however, in respect of some of the achievements. For starters, there is no ignoring the fact that the new substitutes for HCFC-22, chiefly R410A, have a high GWP and by extension an adverse effect on climate. The climate change battle is thus a great deal bigger than the eventual phase-out of HCFC-22. Research into alternative, optimal technologies will necessarily remain a key component of this climate change war. Secondly, the positive economic, social and environmental lag indicators of Botswana's HPMP remain somewhat inconsistent with some of the crucial lead indicators, including training, legislation, information dissemination, control of trade in ODS and disposal of ODS, in regard to which the country was found wanting. Optimistically, one cannot help but surmise that wholesale closure of the gaps in those fundamentals could even speed up both the phase down and the eventual phase-out of HCFC-22. Alternatively, assuming the inconsistencies are a function of information gaps, whether by design or by default, it still remains an urgent imperative that all parties own up to and deal with the reality. Failure to address climate change is simply not an option; if not for current generations, at least for posterity.

CHAPTER 7

COMPARISON OF BOTSWANA AND SOUTH AFRICA'S HCFC-22 PHASE-OUT MANAGEMENT STRATEGIES AND IMPLEMENTATION BASED ON THE MONTREAL PROTOCOL RESOLUTIONS

7.1 Introduction

Based on a regional and economic context, the management of HCFC-22 phase-out in Botswana was compared to SA's HCFC-22 phase-out management strategies and implementation based on MP resolutions. It was therefore worth comparing the phase-out strategies of the two countries since the bulk of HCFC-22 consumed in Botswana is imported from SA. Data analysed were taken from the reviewed documents, interviews and questionnaires.

7.2 Botswana's and South Africa's HCFC-22 phase-out strategies

The Botswana and SA governments have supported an approach to protect the ozone layer as the main factor for sustainable development by promoting the decision of the 19th Meeting of Parties to the MP to adopt an accelerated phase-out of HCFC-22. According to the UNEP (2016a), Decision I/12E of the MP classified Botswana and SA as developing countries (Article 5 countries). As stated in section 2.12.2.1, SA was granted the developing country status under the MP in the ninth meeting after its application for the status, as it had a lower per capita consumption of ODSs.

7.2.1 Import and export licensing system

In the light of Article 4B of the MP resolution, member countries were required to establish and implement a licensing system for importing and exporting controlled substances listed in Annex C. Interview results from the NOU and the UNEP (2016d) respectively, revealed that both Botswana and SA had established a licensing system for the import and export of HCFC-22. In Botswana, the NOO oversees the licensing and quota system for all HCFCs. Findings from the interviews showed that all (100%) importers/companies had applied for import permits by 2015. Observation and interview results indicated that all nine surveyed companies had been issued with trade licences for the importation and distribution of ODSs by the Ministry of Trade and Industry upon approval by the NOO but all (100%) of the HCFC-22 importers and customs officers reported that the licensing system for Botswana was not fully functional. This was despite Botswana reporting the functioning of the licensing system, effected in December 2014, at the 54t^{h} meeting of its implementation.

According to UNIDO (2017), in SA, the licensing system applies to all importers and exporters of HCFC-22. To guarantee complete phase-out of HCFC-22, import permits and quota allocation at every entry port have been operational. The UNEP (2016d) reported that, in SA, quota allocations for import licences for ODSs became operational from 1 January 2013, and licensing requirements for all purchasers of controlled refrigerants as of 1 January 2015. The SA HPMP indicated that in SA 81 companies had import and export licences, with the ITAC issuing trade permits upon recommendations by the NOU (South Africa Trade and Industry Chamber, 2012). The bodies responsible for the control of imports and exports of ODSs in SA are SARS and Customs and Exercise. The DEA (2016) reports allocating HCFC import quotas to all importers (about 19 companies) of pure and blended HCFCs. Quota allocations ensure that only limited or allocated quantity of HCFCs, whether in pure or blended form, are imported by companies.

Specifically, SA's ODS import permit/licence has a duration of four months, renewable by importers at the same intervals (RACA, 2017). The purpose is to keep control and monitor the imports. However, the permit system in SA has been mired in controversy (*ibid*.). One point of contention has been the validity of import permits and allocation, which has been said to be for the calendar year in which they were issued, meaning they cannot be carried over from one year to another. The result has been that reporting to the parties to the MP becomes complicated and stakeholders simply could not agree on the correct position (RACA, 2017).

Botswana's import permit, on the other hand, is valid for a longer duration of twelve months (GoB, 2014b). However, it is worrying that all nine importers reported that they had never been asked to produce a permit at any entry point, with their consignments passing through the entry points without being checked for ODSs. This suggests that enforcement of border controls is still lax. SA's licensing and quota systems are computerised, hence all its exports to other countries, including Botswana, are easily tracked.

When importers reach the port of entry, they are supposed to produce the import licence with the allocated quota which shows the specific amount they are supposed to import per period. However, this is not currently happening. In the survey, all the custom officers (100%) indicated that they do not have import quotas for each licensed company. Importers of ODSs identify themselves using ODS import licences. The custom officers (100%) indicated that they also do not have a list of companies that are allowed to import ODS and they rely on the import licences that importers produce at the entry points. They also indicated that they do not use custom codes to track the quantity of imports, which makes it difficult to track and monitor the entry of HCFC-22 into the country. Thus, quite clearly, the administrative controls on importation of HCFC-22 into the country are not as tight as desired, and companies might well be importing more than is needed to keep consumption in line with MP limitations. In fact, it is quite possible that the claimed reductions in HCFC-22 consumption might not be an accurate reflection of the outcomes of the country's HPMP.

7.2.2 Reporting of data

The NOOs of both Botswana and SA, with help from the UNEP, are liable for reporting, coordinating and monitoring the progress of HPMP implementation (UNEP, 2016c; UNEP, 2018a). Article 7 of the MP requires each country to submit to the ozone secretariat separate data on annual imports and exports of HCFC-22. Both SA and Botswana report annual imports of HCFC-22 to the UNEP. In fact, SA reports both imports and exports of HCFC-22, while Botswana only reports the imports as it does not export any HCFC-22. As at 2015, data reporting for both countries was consistent (UNIDO, 2017; UNEP, 2018a).

UNIDO (2017) reports the existence in SA of a sophisticated import and export control system for HCFCs. The system is operated by ITAC and the whole SARS revenue collection system is founded on it. Import data for all ODS alternatives, including HCFCs, substances containing HCFCs, HFCs and substances containing HFCs are derived from the SARS database. The 2013 to 2017 HCFC-22 import figures for Botswana, as gathered in this survey and as reported in Table 5.1, indicate that the Botswana NOO is up to date with the reporting of data to the UNEP. However, there is still a need to reassess the accuracy of the data submitted by the NOO to the UNEP to verify that there are no discrepancies between the feeding sources like BURS and importers, who all report HCFC-22 data to the NOO, according to study findings. The expectation, logically, was that there should be no difference between importers, BURS and NOO data reported to the UNEP. Unfortunately, the findings revealed that despite consistency in reporting, some significant differences existed in the figures reported, especially between the BURS figures and those of the NOU, and among those from BURS and companies. This shows that the Botswana data reporting and collection system lacks accurate reconciliation. At the centre of this inaccuracy seems to be issues of lack of coordination between quantities of

HCFC-22 recorded by BURS, NOU and importers, including the absence of a computerised system that captures quantities of HCFC-22 data instantaneously as it is imported into the country, poor record keeping and challenges relating to classifications of HCFC-22 codes.

Some differences were observed between data reported on imports from China and SA. SA and China respectively exported 10 187 kg and 3421 kg of HCFC-22 to Botswana in 2016 (UNIDO, 2017). The corresponding figures for the two HCFC-22 exporters, from the BURS, were 12 073 and 10 624 kg. The year's total, as reported by UNIDO was 13 608 kg. There were discrepancies between figures from other sources, as the Botswana NOU reported 170 600 kg and surveyed companies 113 363.2 kg of HCFC-22. This suggests that gaps still exist in tracking and monitoring exports and imports of HCFC-22 across the whole value chain. Figure 5.2 indicates how wide the internal reportage discrepancies are.

As reported in section 2.12.1 of the literature review, SA is currently the biggest importer and exporter of HCFC-22. Companies in SA report their consumption straight to the DEA and the SARS database has been used as a primary source of import data for HCFC-22 (Oppelt *et al*., 2015; UNIDO, 2017). The main applications of HCFC-22 in SA are in assembly, installation, service and maintenance of refrigeration and air conditioning, as well as in the manufacture of extruded polystyrene and aerosol production. In Botswana, the main applications of HCFC-22 are for the servicing of refrigeration and air conditioning equipment. As at 1 September 2015, no imports of any new or used RAC equipment with HCFC-22 were permitted into SA.

7.2.3 Non-compliance Article 8

The MP requires parties found to be in non-compliance to follow procedures set for reporting non-compliance (UNEP 2016a). In 2002, Botswana was in non-compliance with its obligation under Article 2H of the MP. To ensure return to compliance, Botswana submitted her plan of action for measures for controlled substance in Annex E and reported the functioning of its licensing system at the 54th meeting of its implementation (UNEP, 2018d). The licensing system was effected in December 2014. SA has never experienced issues of non-compliance. Specifically, as reported in section 5.5.1, the DMS indicated that importers had been issued with an import licence and there were ten companies in the country legally allowed to import ODSs into the country.

7.2.4 Research, development, public awareness and exchange of information

7.2.4.1 *Research*

An important part of the MP resolution is research and to facilitate the transfer of technology, especially into environmentally friendly alternatives to HCFC-22 (UNEP, 2016a). For its part, the Government of SA has undertaken initial engagement activities through stakeholder meetings and publications and is organising workshops to engage industry, introduce the HCFC-22 reduction strategy, and give access to technology experts, as well as present studies and pilot projects undertaken in SA (DEA, 2018a).

Specifically, the DEA hosts the quarterly HCFC stakeholder meetings, alongside which are also held the HCFC Project Steering Committee (PSC) meetings. The purpose of these meetings is to coordinate the effective monitoring and implementation of the HPMP in the country. The relevant stakeholders are government and industry, namely, industry associations and the implementing agency (i.e. UNIDO) (DEA, undated).

As reported in section 5.6.4, Botswana's HPMP promotes the adoption of HCFC-22 alternatives as one of the main activities of the phase-out plan. Specifically, end users are urged to replace their old HCFC-22 equipment with alternative equipment using R410A, R134A, R505 or HFC-32. The challenge though is the absence of a supporting legal framework banning the importation of HCFC-22 equipment, as the legislation in place focuses on the importation of HCFC-22 itself for servicing and repair purposes. Consumers therefore still freely purchase HCFC-22 equipment. While awareness of these alternatives is higher among companies, there might be a little of it among individual consumers.

The RACA (2017) reports that one such quarterly stakeholder meeting took place on 29 June 2017, drawing role-players from across the country to debate critical issues surrounding refrigerants in SA from tariff headings to reclamation. This meeting took place at its traditional venue, the DEA's head office in Pretoria. It was, according to the RACA (2017), well attended by both industry stakeholders and government officials. At this meeting, HCFC stakeholders discussed the issue of four pieces of ODS reclamation equipment donated by UNIDO which were waiting to be transported from Europe to SA. There was a discussion on the geographical positioning of the donated ODS reclamation equipment and the need for the required infrastructure to set up the equipment. Stakeholders suggested setting up a pilot project first before shipping the equipment to SA.

The importance of custom tariff headings for all refrigerants, especially all ODSs, was again highlighted as this plays a key role in the control and monitoring of imports and the allocation of quotas. The ITAC and SARS were supposed to give feedback but the matter was moved over to the next meeting (RACA, 2017). Proper custom tariff headings for all refrigerants are needed to control imports/exports, including headings for pre-charged systems. But this still hasn’t been finalised.

As reported in section 5.6.4, Botswana’s HPMP promotes the adoption of HCFC-22 alternatives as one of the main activities of the phase-out plan. Specifically, end users are urged to replace their old HCFC-22 equipment with alternative equipment using R410A, R134A, R505 or HFC-32. The challenge though is the absence of a supporting legal framework banning the importation of HCFC-22 equipment, as the legislation in place focuses on the importation of HCFC-22 itself for servicing and repair purposes. Consumers therefore can still freely purchase HCFC-22 equipment. While awareness of these alternatives is higher among companies, there might be a little of it among individual consumers.

In the case of SA, Brophy (2016) acknowledges the existence of some challenges that still need resolution, including questions relating to alternatives to HFCs and their costs, urging the assessment panels to work further to find alternatives over time. The DEA (2018a) asserts that the transition of the local RAC industry to safer alternatives has been smooth, and this positive trend should be boosted by the availability of machines for the recovery, reclamation and recycling of ODSs. This is in keeping with one of the chemicals and waste initiatives on recovering, reclaiming and recycling ODSs (DEA, 2018a).

As part of technology transfer efforts, May 2018 saw the holding of the first regional workshop in Africa, in Gaborone, Botswana’s capital, to promote energy-efficient cooling (UNEP, 2018b). Key stakeholders, numbering over 90 and coming from 54 governments, were those responsible for managing compliance with the MP on substances that deplete the ozone layer, as well as those who craft national energy policies (*ibid.*). This was hailed as a success in starting a “twinning” dialogue between the ozone officers and energy officials, and beginning the flow of information at the national level on the energy efficiency and refrigerants nexus (*ibid.*).

7.2.4.2 *The development of programmes/initiatives to facilitate ozone depleting substance phase-out*

One of the requirements of the MP is for member countries to develop programmes that would encompass workshops, demonstration projects, training courses, the exchange of experts and the provision of consultants on control options, in keeping with the unique needs of developing countries, for the consideration by the parties at their second meeting (UNEP, 2018d).

The Government of Botswana established the BRACA to work with the NOO in carrying out awareness campaigns, the training and certification of technicians and the management of the informal sector (as reported in section 5.6.3). The South African equivalent is the South Africa Refrigeration and Air Conditioning Contractors Association (SARACCA), which is an independent association comprising individual contractors who have jointly agreed to establish a set of governing standards on refrigeration and air conditioning. From a legislative point of view, SA has gazetted a number of instruments to control imports and exports of HCFC-22 (as reported in section 2.12.2).

Botswana also established the NOU in 1992 in the Department of Meteorological Services with the help of the MLF. This NOU is a focal point charged with, among other things, data collection and reporting to the Ozone Secretariat, raising awareness to both the industry and the general public. Additionally, the NOU facilitated the development of the national ozone regulations (Ntakhwana, 2018). The country has taken robust steps to institutionally strengthen the national ozone office for the implementation of projects such as the refrigeration management plan for setting the scene for phase out of ODSs (UNIDO, 2015; UNEP, 2018a). The strengthening of enforcement officers such as customs officers, refrigeration and air conditioning experts and BRACA saw the country achieve a 10% HCFC-22 reduction in 2016, with projections that continued activities will result in the country achieving the 35% reduction by 2020 in line with the phase-out schedule (Ntakhwana, 2018).

7.2.4.3 *Public awareness*

The report shows that both Botswana and SA have in place programmes which are meant to raise awareness of the HCFC-22 phase-out (DEA, 2018a; Section 5.6.3). SA has targeted its awareness efforts at enforcement officers and the general public, with a specific focus on legal instruments and policies concerning the phase-out of HCFCs and equipment containing the same. Section 2.12.2.6 indicated that a road show was successfully carried out on 14–21 June 2018; this created a platform for deliberating ozone-depletion related issues and enabled information sessions for updating on progress made and new work or initiatives on the horizon (DEA, 2018a). SA and Namibia have established a collaborative industrial awareness campaign for knowledge sharing of ODS phase-out and available alternatives (DEA, 2018a). For the efficiency and compliance of the collaborative programme, Koegelenberg (2018) expressed the need for a closer relationship between the two countries to minimise illegalities at entry ports. There is also an opportunity to strengthen cooperation between the two countries.

As reported in Section 5.6.3, awareness programmes in Botswana are promoted through the BRACA whose membership includes ODS distributor companies, customs officers, technicians, refrigeration lecturers from technical colleges and fire fighters. According to UNIDO (2015), BRACA's main roles are to share information among stakeholders on ODS phase out and to coordinate the country's training programmes in conjunction with the NOO. Information sharing is done through various meetings, workshops and conferences for members and the public. Also used thus far have been media and the yearly celebration of International Ozone Day (UNEP, 2019d). However, the NOO has reported slow progress on the part of BRACA in sharing information because most of its members are from private companies and are always busy (*ibid.)*.

7.2.4.4 *Exchange of information*

Botswana has embarked on the training of BURS officers to enable them to identify HCFCs and prevent illegal trade (Letsholo, 2019). Side by side with this is the training of RAC technicians, and the main institution doing that is the Gaborone Technical College. Study results revealed that Botswana has also capacitated different committees responsible for ozone monitoring, for example the Licensing Committee. The Botswana NOU and the United Nations (UN) Environment Economy Division jointly organised and attended the Joint Network Meeting of National Ozone Officers for 54 African countries held in Gaborone from 21–23 May 2018 (UNEP, 2018b). The meeting provided an interactive forum for national ozone officers to develop skills, share ideas and exchange experience with their counterparts in order to comply with MP resolutions. Importers and distributors of ODSs are also required to disseminate information on the HCFC-22 phase-out to their customers.

SA has similarly trained customs and law enforcement officers in identifying, monitoring and controlling HCFCs and HCFC-containing equipment. However, it is reported by the DEA (2018a) that industry players were reluctant to accept the phase out of HCFCs, hence the DEA promised to organise more training workshops for good refrigeration management practices for both formal and informal sectors. SARACCA pledged to raise awareness of the HCFC-22 ban and promotes the use of alternative refrigerants. In addition, it conducts short courses in good refrigeration practices and numbers of technicians in the RAC informal servicing sector are increasing. Although BRACA takes part in the training of technicians, SARACCA seems to be doing more in terms of raising awareness and training of technicians in the informal sector. BRACA can learn from SARACCA how to conduct training with RAC technicians from the informal sector, as the UNEP (2019d) reported that in Botswana gathering RAC technicians from the informal sector has not been successful.

The key challenges, however, are the lack of accessibility of technicians in the informal servicing sector and the lack of relevant training and awareness of registration processes (DEA, 2018a). To try and deal with the former challenge, the DEA drafted a letter to RAC equipment distributors/wholesalers to assist with identifying and acquiring contact details of technicians in the informal service sector. RAC technicians in the informal service sector are encouraged to register their contact details at the DEA exhibition stands for this initiative for the development of a database (*ibid.*).

Interview results from this study revealed that currently no information exchange takes place between Botswana’s RAC contractors association and those in SA. The UNEP (2019d) reported two joint border discourses conducted between Botswana and Zimbabwe in 2018 and between Botswana, Zambia and Zimbabwe in 2019. The dialogues aimed to exchange information on common entry point challenges and their remedy and the possibility of coordinating import permits and legislation in the region. In fact, according to the DEA (2018a), SA seeks to establish joint customs and excise training to strengthen the enforcement at border posts, to encourage South African and Namibian NOU cooperation regarding ODS importation, as well as to encourage cooperation between RAC associations in SA and Namibia on ODSs and alternatives information sharing and strengthen training.

7.2.5 Financial mechanisms for HCFC-22 Phase-Out

Based on the HCFC baseline consumption in the servicing sector of 200.1 MT (11.00 ODP tonnes), Botswana's allocation up to 2020 for 35% reduction phase-out was to be a US$560 000 in line with MP decision 60/44. However, owing to delays in submission and change of implementing agencies, the allocation could not be included in the 2015–2017 business plans for the UNEP and UNIDO (UNEP, 2018e). A total of US$302 350 was requested for the period 2015–2017, with the UNEP allocating the funding for Botswana in its 2016–2018 business plan (UNEP, 2018e). The actual funding disbursed to SA, as of March 2016, was US$2 920 698, representing 64% of the approved total funding of US$4 552 849. The balance of US$1 632 151 was to be disbursed in 2016 (UNEP, 2016d). The disbursed funds were to be used to implement the third tranche of the HPMP, mainly involving putting in place additional legal instruments to control supply and demand of HCFCs, implement various initiatives targeting alternatives to HCFC-22 in the refrigeration servicing sector, as well as monitoring activities targeted at importation and exportation of HCFCs, including training of customs officials and information dissemination and awareness raising. The MLF funding for the two countries differs because of differences in HCFC-22 consumption. With the financial assistance from the MLF it is expected that the proposed plans of action for HCFC-22 phase-out for both Botswana and SA should work well.

7.2.6 Transfer of technology

Article 10A of MP through the financial support mechanisms ensures that the best available environmentally safe substitutes for HCFC-22 and related technologies are transferred to developing countries (UNEP, 2016a). In line with Article 10A, alternative refrigerants are presently used in both SA and Botswana, with R404A, R407C, R410A. R507A and HFC-134a refrigerants being commonly used in both countries (UNEP, 2016d; DEA, 2018a; UNEP, 2018d). There is also increased use of hydrocarbons (HC) and ammonia, both with low GWPs.

As discussed in Section 5.6.4, an important part of the MP resolution is ongoing research and efforts and initiatives to facilitate the transfer of technology, especially into environmentally friendly alternatives to HCFC-22. The UNEP (2017e) reported that in SA's first stage of HPMP implementation, some projects have been approved for systems houses to customise formulations using new and emerging low-GWP alternative technologies (methylal, methyl formate and hydrofluoro olefin (HFOs)) to supply indigenous downstream users, many of them being small to medium enterprises (SMEs). The first six downstream users supported by their systems houses were converted to methyl formate. At the centre of Botswana's HPMP is the promotion of the adoption of HCFC-22 alternatives (UNIDO, 2015; UNEP, 2018a). Awareness of these alternatives is high among importers; not so among end users. As part of these efforts, the country's DMS encourages end consumers to replace their old HCFC-22 equipment with alternative equipment. As revealed by the interview results of this study, what remains a challenge is the absence of legislation banning the importation of HCFC-22 equipment, with current legislation controlling the importation of HCFC-22 itself only for servicing and repair purposes. Thus, concerns about the replacement costs and the servicing and repair costs are also some of the impediments slowing down the switchover to alternative technologies (UNEP, 2018a). At the centre of the impediments to reforming legislation is the question of funding; there are doubts that the US will fund the smooth transition in terms of HFC phase down after the Kigali meeting, following the change in administration in that country. Thus, the DEA reported regulatory reform matters had been temporarily halted pending resolution of the funding question (RACA, 2017).

7.2.7 Meeting of the parties to review HPMP implementation

Article 11 requires parties to the MP to hold meetings and review implementation of the HPMP and decide on any adjustments where needs be. In SA, the DEA hosts HCFC stakeholder meetings which are held quarterly. Stakeholders (Industry Associations and Implementing Agency, UNIDO) meetings are held parallel to the HCFC Project Steering Committee (PSC). The main objective of both meetings is to facilitate a coordinated approach to monitoring and implementing the country's HPMP effectively (DEA, 2018a).

Stakeholder meetings have also taken place on the adoption and enforcement of the HCFC control measures promulgated. The measure to establish mandatory recovery and recycling of HCFCs and other refrigerants, originally planned by 1 September 2014, was negotiated with sector counterparts in that year with the expectation that is would be established during the first half of 2017. For its part, Botswana holds regular consultative workshops for stakeholders on the HCFC-22 phase-out. The consultative workshops/meetings are held to determine the HPMP strategy in Botswana (UNIDO, 2015; UNEP, 2018a, 2018e).

7.2.8 Disposal and destruction of controlled substances

Parties to the MP agreed to adhere to international and national standards for ODS destruction facilities. Botswana is aware of Decision XII/8 and has pledged to use natural refrigerants through equipment replacement rather than retrofitting. However, there is no destruction facility in the country, nor, as reported in Section 5.7, disposal centres for equipment using ODSs.

In SA, the issue of waste management has not been adequately dealt with (Heating Ventilation Air Conditioning and Refrigeration (HVACR, 2018). According to the UNEP (2018e) SA has an ODS destruction facility managed by one of the importing companies; however, there is still no clarity on whether the destruction facility is being used or not (RACA, 2017). In addition, the DEA mandates municipalities to coordinate the disposal of scrap fridges and air conditioners using disposal guidelines in line with the Waste Management Act and other regulations (DEA, 2018b). The following additional measures were instituted as part of the entire refrigerant recovery effort. The country has made the declaration gas recovery mandatory. It has also introduced incentives to promote the recovery of HCFCs and for workshops to extract HCFCs from imported equipment (cars). A list of contact details of the technicians that have been trained in conducting retrofits has been circulated (UNEP, 2016d). Although there are these good initiatives for the recovery of refrigerants, the HVACR (2018) reported that SA still lacks sufficient destruction facilities for the reclaimed refrigerant and the DEA has suggested introducing a waste licence which will allow feasibility of shipping the waste outside its borders. However, discussions on the waste licence requirement initiative are still on-going with the DEA and other departments.

7.2.9 Monitoring of international trade and prevention of illegal trade in ODS

In response to Decision XII/10, SA initiated the training of customs officers and distributed refrigerant identifiers to all entry points into the country. In addition, the country's revenue collector, SARS, successfully allocated tariff codes to identify ODSs (UNEP, 2016d). As reported in section 5.6, in Botswana, customs officers at all major ports of entry have been trained in controlling and monitoring the ODS trade. As of December 2018, interview results revealed that Botswana had three gas identifiers, but those had not yet been distributed to all entry points. The country plans to have more refrigerant identifiers distributed to all major ports to help curb illegal trade in ODSs and ODS-dependent appliances (Letsholo, 2019).

As reported in section 5.5.4, a recent report by Letsholo (2019) painted a more positive picture, with indications that the DMS has given eight refrigerant identifiers to BURS in pursuit of the fight against the illegal importation of ODSs. This brought the total of refrigerant identifiers that will be distributed to Botswana's ports of entry to eleven. This is, however, inconsistent with the findings of this study. On one score, results from this study revealed that there are no refrigerant identifiers that are currently used by customs officers to accurately detect the type of refrigerant gas passing through the ports of entry. On another score, while the DMS stated that there were only three refrigerant identifiers available for use at the country's entry points, the interview with the NOO revealed that the three refrigerant identifiers had not yet been distributed to the ports of entry for use by customs. In any case, even if they had been distributed, these three refrigerant identifiers would still be inadequate considering that there are at least 26 ports of entry in the country.

In SA, the HVACR (2018) reported that the use of refrigerant identifiers to detect illegal substances at entry ports by customs officers is still a challenge. The three entry ports visited by the DEA compliance team to inspect compliance on use of refrigerant identifiers by SARS officers revealed none used the instruments, with officers only doing random inspections and solely relying on documentation to see what is brought into the country. The SARS officers also carry out physical inspections if they are suspicious of illegal trade in refrigerants (*ibid*.). From the DEA compliance team inspections, it is revealed that SA entry ports have refrigerant identifiers but there are not used by the responsible officers. In both Botswana and SA, therefore, the use of refrigerant identifiers at entry ports is inadequate and this may result in illegal trade in MP controlled substances.

As discussed in section 5.5.2, Botswana's quota system does not target individual companies, but the entire industry, in this case ten companies. The NOU then asks individual companies to reduce their annual imports by the percentage required to meet the targeted milestone for that year (section 2.12.1.1). The expectation is that adherence to target consumption reductions by all individual companies will result in an industry-wide reduction in consumption. Happily, the survey results indicate high levels (100%) of compliance by importers to the NOU import quota restrictions set annually (as reported in section 5.5.2). Part of the restrictions on HCFC-22 come by default from the South African end for those companies who import from SA, by virtue of that country's own policy. There are, however, no policies restricting HCFC-22 imports from China. There has been criticism of the industry-wide quota approach on the basis of its unfairness, as some companies can get away with individual non-compliance. Interview results from both the NOO and importers of HCFC-22 revealed that there has been no situation where some companies could not import HCFC-22 because the quota had been used up at their expense.

Liedtke (2017) reported an all-out campaign by the South African government to stamp out the smuggling of ODSs into the country. This involved training of customs and enforcement officers and provision of appropriate illegal ODS detection and analysis equipment to land, sea and air ports of entry, including Beitbridge, Cape Town, Durban and Port Elizabeth.

7.2.10 Measures to facilitate the monitoring of trade in hydrochlorofluorocarbons and substituting substances

In response to Decision XXVI/8, SA put in place additional legal instruments to control the supply and demand of HCFCs, for which exercise no funds were requested. It also planned to continue working with SARS and ITAC to address the modifications required to tariff codes and improve monitoring and reporting; This was in light of the country's observation at the HPMP preparation stage that the current customs tariff does not have appropriate codes for recording the import and export of some blends containing HCFCs, including HCFC-22 and HCFC-142.

For its part, according to UNIDO (2015), Botswana has gazetted its ODS Regulations in 2014 under the National Meteorological Services Act 2014. The regulations control the importation and exportation of ODSs, as well as products containing and dependent on ODSs. The regulations, inter alia, put in place measures to control the consumption of HCFCs by restricting the importation and promoting the retrofitting of HCFC-based equipment. In order to control the importation and consumption of HCFCs, a quota-based system has been operationalised. The system further puts in place a mechanism to verify facilities handling HCFCs to ensure that they have adequate human capacity and equipment to manage HCFCs in an environmentally sound manner. These facilities are subject to regular checks by the ozone office to verify that they comply with the set standards.

7.3 **Conclusion**

While both SA and Botswana have made concerted efforts to meet MP requirements, their levels of compliance have clearly been disparate. SA's import permits and a quota allocation system for controlled substances, as well refrigerant identification, have been operational at every entry port, while Botswana's is not fully functional. In fact, the monitoring system for the movement of controlled substances remains lax in Botswana. In particular, SA generally has never experienced situations of non-compliance, with an accurate computerised licensing and quota reporting system that enables all imports and exports to be tracked. Both countries have been active in awareness raising and training activities, but awareness in Botswana remains deficient among end users. Botswana's legal framework remains inadequate as it does not ban the importation of HCFC-22 dependent equipment; this stifles the switchover to HCFC-22 alternatives. Botswana has no destruction facility in the country, nor does it have disposal centres for ODS using equipment, while SA has. On the bright side, survey results indicate high levels (100%) of compliance by importers to the NOU import quota restrictions set annually.

CHAPTER 8

SUMMARY OF FINDINGS, CONCLUSIONS AND RECOMMENDATION

8.1 Introduction

This thesis evaluated the HCFC-22 phase-out management systems and its environmental implications in Botswana. This chapter therefore attempts to synthesise and incorporate the major findings and conclusions and provides recommendations/suggestions for various stakeholders. The chapter links the objectives of the study indicated in Chapter 1 with the main findings of the study. It then indicates the contributions of the study to the body of knowledge, practice and policy. The chapter closes by suggesting issues necessitating further research.

8.2 Summary of main findings

8.2.1 The levels of awareness and product knowledge of service stakeholders in the importation and distribution of HCFC-22 in Botswana

This objective concerned the level of product knowledge and awareness of the HCFC-22 phase-out plan (HPMP) of stakeholders in Botswana. The bulk of the respondents possessed moderate levels of product knowledge, although there were notable inter-group variations. In particular, consumers had higher levels of awareness than other officers, indicating gaps in awareness raising and training. This difference belies the fact that the bulk of the respondents are relatively educated (certificate and diploma holders) and experienced (6–15 years), and suggests that there have simply not been enough awareness-raising efforts on the part of BRACA and other entities charged with this responsibility.

8.2.2 The Botswana's HCFC-22 phase-out management system

This objective focused on evaluating the Botswana HCFC-22 phase-out management system. From both a lag and lead indicator's perspective, and based on observations from phase 1 of the HPMP, it appears safe to say Botswana does not just have a HCFC-22 phase-out management system, but a functional and, thus far, effective one. A number of observations bear this picture out. The country's 2018 project proposal and projects scope report, both involving standard independent verification of facts, confirmed a number of crucial matters. This was importantly, the consistency between HCFC-22 sector consumption data reported by the Government of Botswana under the 2019 implementation report and the data reported under Article 7 of the MP. The gaps that still exist however, seem to relate not to the quality of engagement with stakeholders, but to the frequency, especially as regards the private sector. The latter point is essential as ultimately, without stakeholder buy-in, implementation of any project is unlikely to be optimal and sustainably effectual.

8.2.3 Level of compliance of Botswana to the MP resolutions on the monitoring, consumption and phasing out of HCFC-22

This objective focused on Botswana's level of compliance with the MP requirements and ODS regulations. HPMP awareness was found to be low and awareness with ODS regulations to be high. Correspondingly, perceived levels of compliance were largely moderate to high, especially in regard to non-regulatory elements of the phase-out plan rather than the regulatory elements. Gaps were also noted in respect of the industry-wide quota system, data reporting, prevention of illegal trade in ODSs, training of service technicians, knowledge of alternatives as well as disposal of ODS equipment.

8.2.4 Milestones in HCFC-22 phase-out trend pursuant to the Montreal Protocol

This objective evaluated the strides that Botswana had made in achieving the HCFC-22 phase-out milestones. The overall HCFC-22 consumption decreased for the first stage, 2013–2015. This decrease was calculated at 10.5% and was slightly more than the 10% reduction expected. A steady decrease in HCFC-22 consumption was noted towards the 35% target for 2020, largely thanks to awareness-raising initiatives directed at the DMS, customs and importers. This despite the implementation challenges experienced, including lack of adequate funding, lack of ODS storage and destruction facilities, government red-tape, an inadequate regulatory framework and the uncompetitive prices of alternatives to HCFC-22.

8.2.5 The implications of phasing out HCFC-22

This objective focused on evaluation of the implications of phasing out HCFC-22 in Botswana. Generally, it emerged that HCFC-22 phase-out had reduced HCFC-22 consumption by approximately 510 400 kg from 2011 to 2017, translating to 28 072 ODP saved. On a positive note, the HCFC-22 plan saved the country 128 kWh of electricity for the period 2009–2017.

8.2.6 South Africa's and Botswana's HCFC-22 phase-out management strategies and implementation based on the MP resolutions

This objective focused on comparing the levels of compliance of Botswana and SA to the requirements of the Montreal Protocol. It turned out that their performance was disparate, with

SA never having experienced non-compliance, and therefore faring far better than Botswana. This was especially in terms of its permit and licensing system, ODS destruction and ODS equipment disposal, as well as its legal framework.

8.3 Conclusion

While Botswana seems to be doing well in terms of complying with the non-regulatory elements of its HPMP, significant work still needs to be done in respect of the regulatory elements. One particular area requiring attention is the extension of legislation to cover not just HCFC-22 and other refrigerants, but equipment dependent on them. The existence of gaps in terms of the country's quota system, data reporting, prevention of illegal ODS trade, service technician training, user knowledge of alternatives and disposal of ODS equipment represents other instances of shortcomings on essential lead indicators of the success of the country's HPMP. Thus, while reported HCFC-22 importation figures indicate a steady decrease towards the country's stepped targets and the ultimate 2030 phase-out goal, there is still an evident discrepancy between the lead indicators (regulatory, non-regulatory and financial antecedents of HPMP success) and the lag indicators (the economic, environmental and social impacts of the HPMP).

One must therefore be conservative in one's assessment of the success of the country's HPMP in view of the evidence of these challenges. In fact, in all probability, HCFC-22 consumption could still be higher than claimed or reported. The corollary to this is that the effectiveness of the MP might be overstated. Thus, while there is no discounting the significant work thus far done, still more work needs to actually be done to establish, strengthen and tighten the legal, administrative, logistical and enforcement infrastructure and arrangements for effective implementation of Botswana's HCFC-22 phase-out plan.

8.4 Recommendations

8.4.1 HCFC-22 awareness

There is no doubt that stakeholder awareness of the existence of the HPMP, and of the alternative technologies to HCFC-22, is crucial for the success of the HPMP. The study revealed gaps in awareness among key stakeholders in terms of these two crucial aspects, despite some initiatives that included road shows, workshops and various media: print, radio and television having been implemented by the NOU. Of note to the researcher is the fact that the frequency of awareness-raising initiatives might not be sufficient, and this needs to be increased to make an impact. Secondly, there might be a need to carefully select the communication media used in line with the media consumption habits of target markets. Traditional media such as radio and television possibly result in wasted coverage since the majority of people, professionals and non-professionals alike now spend significant amounts of time on social media, including Facebook and WhatsApp. Communicating through popular, widely accessed social media would ensure the messages have a higher chance of reaching targeted stakeholders. In addition, print media like posters in heavy traffic areas, including border/entry ports, would obviously reach final users, a constituency that the study revealed had low levels of awareness of the HPMP and alternative technologies to HCFC-22.

To augment the efforts stated above, the NOU could also provide copies of the ODS regulations at every port of entry and to all customs officers. In fact, awareness raising must start from the grassroots. On a fundamental level, the NOU may need to collaborate with primary schools to participate in awareness campaigns, for example poster making, essay and slogan competitions. Similarly, at intra-company level, it would help to raise awareness among employees if companies were to incorporate updates for employees on ODSs and phase-out progress during daily briefings and meetings.

8.4.2 Familiarity of stakeholders of HCFC-22 refrigerants with the National Meteorological Act and other legislation

The study also revealed that a significant number of stakeholders, in particular customs officers and consumers, were not familiar with the National Meteorological Act, 2014 and the ODS regulations, 2014. This suggests the need for a holistic, multipronged approach to information dissemination. For one thing, information gaps on the part of customs officers might mean there is no buy-in from players who should be enforcing compliance with legal requirements. For another, lack of awareness on the part of consumers might mean slow uptake of new, environmentally friendly technology, which defeats the purpose of the HPMP. One clear area of need is stakeholder buy-in. Thus, in terms of approach, the regulatory authorities must develop partnerships between industry, customs, government and the community at all levels. Operationally, this might require the regulatory authorities to conduct regular consultation meetings with BRACA and all stakeholders on ODS phase out.

8.4.3 Greater bilateral cooperation between Botswana and South Africa

The movement of refrigerants across borders inevitably involves multiple legal and administrative systems. Thus, no country can successfully control ODS trade and movement without the cooperation of others, especially its trading partners and neighbours. Individual countries might need to enter into bilateral agreements for the control of trade and the movement of ODSs and associated equipment, and the recovery of HCFC-22. In the case of Botswana, a bilateral agreement with SA is a definite requirement as SA is Botswana's biggest source of HCFC-22. A similar agreement with China, a major source of ODS-dependent equipment, would help control the movement of the same.

On a macro-level, Botswana needs to facilitate international communication networks to allow international exchange of information on ODSs. Operationally, each entry point in the country needs to collaborate with its neighbouring entry port and share information on the ODS phase out. Customs officers need to network and exchange information on ODS with neighbouring countries.

8.4.4 Improving compliance levels of Botswana to the Montreal Protocol resolutions on the monitoring, consumption and phasing out of HCFC-22

- **Training**

Ozone depletion, global warming and climate change in general remain topical, international issues of concern and interest, with numerous adverse impacts on human health and the environment. Current efforts to tackle them are within the frameworks of international conventions, principally the MP and subsequent amendments to it. This might not be enough, however, as the generality of humanity might largely be unaware of the entirety of the ozone depletion menace. One additional way of capacitating more of humanity to take part in efforts to ameliorate the problem would be to extend training beyond current mainstream players, namely, customs officers and refrigeration technicians. To that end, training opportunities must be widened by having more technical colleges develop curricula that deal with HCFC phase out. The same must develop curricula that train technicians on the handling of ODS. In the current dispensation, only Gaborone Technical College trains refrigeration technicians. This might explain the discrepancy between the MP training required of all technicians and Botswana's training output of 300 technicians as of 2015. A particularly important group worth targeting for training and certification are the informal technicians who are already active players in the refrigeration sector, but who might not necessarily be compliant in terms of best practices – similarly, the subcontractors who deal with HCFC-22. Likewise, ozone and environmental protection officers must be trained and certified in order to enhance monitoring and enforcement capacity.

From a customs point of view, aside from the MP training specifications, the researcher found it worrying that 68% of customs officers indicated that they had never received any training on the handling of ODSs. The ultimate target should be to train all customs officers, including new recruits on this, at customs training schools. The crucial importance of this training, the researcher reckons, is such that structured training manuals for custom training should be developed, not mere presentations to attendants. In fact, the trainees should write an examination and a certificate of achievement should be given to successful customs trainees.

Thereafter, because training should be seen as a process as opposed to a once-off event, regular retraining and capacity building of customs officers should be the norm to keep them abreast of changes and developments in the field of ODS handling, identification, monitoring and control. A register of trained customs officers should be kept by BURS and the same information copied to the NOU. Ultimately, to ensure compliance to set standards the NOU should monitor and evaluate the results of training and prepare a follow-up report.

- **Illegal trade and monitoring of HCFC-22 importation**

Several challenges to the monitoring and control of illegal trade and importation of ODSs were noted in the study. The first was the current non-use of customs codes to track the quantity of imports, making it difficult to track and monitor the entry of HCFC-22 and HCFC-22-dependent equipment into the country. This situation obviously compromises the tracking and reporting system, have, codes must be adopted for use. The second was the shortage and, by extension, non-use of gas identifiers and leakage detectors at the 26 entry points. The necessity for each entry point to have and use a gas identifier hardly needs emphasis if illegal ODSs are to be properly controlled. Coupled with this is the need for customs to have a checklist for identifying ODSs and ODS-based products at each entry port.

In the nascent stages of implementation of these measures, BURS might benefit from involving the Botswana Bureau of Standards (BOBS) to help to check imports for proper labelling. The NOU might also consider engaging a private consultant to assist in monitoring activities. Beyond just customs, tougher and more deterrent measures might be required at entry points in order to contain the smuggling of ODSs. For starters, information on the illegality of ODS smuggling must be prominently displayed at these entry points, clearly articulating the serious consequences of any breaches. Obviously, this would require a supportive legislative framework covering both ODSs and ODS-dependent equipment. It would also be a good idea for NOU to be more hands-on by having officers or representatives at every entry point to assist in the monitoring activities. Finally, police should become part of the ODS law enforcement team working with customs officers to gather intelligence and conduct inspections of suspicious imports.

The study also revealed glaring deficiencies in the import licensing/permit system of Botswana. While the ideal situation is that ODS importers are supposed to have licences and import permits indicating their allocated import quota per period, the study revealed that the customs officers did not have a list of the companies allowed to import ODS, relying instead on the import licences that importers produced at the entry points. This points to at least two areas of need: first, it is critical that NOU be known and be fully assisted by BRACA to make sure that the licensing system is working; and secondly, the NOU should develop a comprehensive electronic software system for capturing import information in real time. This information should be web-based and accessible to law enforcement officers, that is, customs officers and NOU. It should then be possible to enter the status and quotas for every importing entity in the system, enabling accurate and timely decision-making by customs officers. It would also help close the reporting discrepancies between NOU, BURS and the importing companies. NOU should have precise records of HCFC-22 imported and exported.

- **Disposal of HCFC-22 and equipment**

Another area of deficiency identified in the study concerned the disposal of old ODS equipment. The National Meteorological Act of 2014 requires that ODSs should be transported, stored and disposed of in an environmentally friendly manner, but Botswana fell short in several respects according to the study findings. One area of need was for the country to have a specific waste disposal place for ODS and RAC equipment, enabling retrofit and recovery of HCFC-22 and other ODSs. SA, Botswana’s major HCFC-22 supplier, has such a facility, and Botswana should simply comply and establish one. The country should also create a recovery unit/reclamation unit to collect gas from existing equipment and train personnel on the procedure for recovery and recycling (reclamation) of ODSs and associated equipment. Should the NOU face capacity challenges in respect of disposal and reclamation facilities, it might be an effective approach to transfer the coordination of the disposal/reclamation issue to local authorities or councils, possibly in cooperation with relevant ministries in keeping with the disposal guidelines in the Waste Management Act of 1998 and other regulatory frameworks.

8.4.5 Impacts of HCFC-22 phase-out

While decreasing demand for HCFC-22, the HPMP had correspondingly occasioned the higher replacement and servicing costs of HCFC-22-compliant equipment, as HCFC-22 substitutes are higher priced. In that vein, and in order to give impetus to technology transfer, the Government of Botswana could offer a number of incentives for the issue of HCFC-22 substitutes. The spirit of these measures would be to make HCFC-22 more expensive than the substitute refrigerants. Three such possible incentives immediately come to mind. One could be a waiver of duty on HCFC-22 substitutes and related technologies. Another could be a discount/tax reduction or tax holiday/VAT reduction on the import of non-ozone-depleting equipment. Alternatively, the government could subsidise the prices of HCFC-22 substitutes in order to close the high price differential between the HCFC-22 and its substitute refrigerants.

At the same time, a number of disincentives could be imposed on imports of ODS, for example high import duty to reduce demand for ODSs and ODS dependent equipment. Similarly, the NOU could hike the fees on the import permits for ODS to discourage the importation thereof. In tandem with all these incentives and disincentives should be renewed efforts to raise awareness of and promote alternative technologies and their associated benefits. In the long term, there will be a need for collaboration between the Ministry of Environment, NOU, key industry players and research institutions to develop alternative technology solutions designed to mitigate the impacts of HCFC-22.

8.4.6 Regulatory

The present regulatory environment is not completely watertight. One glaring gap is its focus on the control of HCFC-22 and other ODS, without covering the associated equipment. As reported in this chapter, policies must be developed which encourage the purchase and use of HCFC-22 alternatives. The starting point after development of such should be for the NOU to make the ODS regulations available to all HCFC-22 dealers to ensure they are aware of what the law requires of them. HCFC-22 dealers are key players in the whole ODS control matrix, and their awareness, knowledge, buy-in and cooperation are crucial for success of the HPMP.

The legislative framework must extend beyond the controlling and monitoring of the importation of HCFC-22 and cover HCFC-22-dependent equipment. Provision must be made for strict checklists at entry points and the studious adherence thereto. The law must also spell out and require strict enforcement of leakage tests, which are currently not being done.

8.5 **Contribution of the study**

8.5.1 Contribution to theory

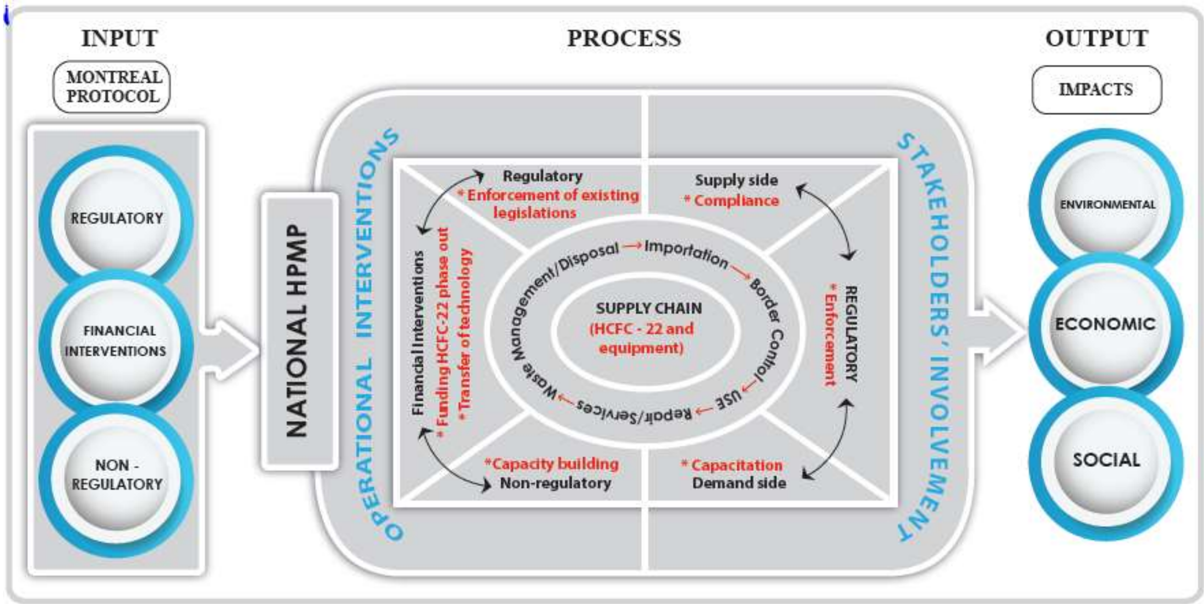


Figure 8. 1: Integrated National Tri-Component HCFC-22 Phase-out Framework

One of the main contributions of this study to theory is the formulation of the Integrated National Tri-component HCFC-22 Phase-Out (INTHPO) Framework (Figure 8.1). The basic premise of the framework is that an integrated systems approach is required for effective implementation of a country's HPMP. There are three components in the model requiring integration and unification: the ODS supply chain flows; stakeholders/players in the HPMP implementation plan; and the key implementation drivers of the HPMP.

The logic of the model is that at the centre of effective HPMP implementation by Botswana must be effective control of the total supply chain of HCFC-22 and other ODSs. Major phases of the supply chain are the production/importation, border clearing and checking, use, servicing/repair, and the disposal of ODSs and ODS-dependent equipment. The effective control of the supply chain flows in turn depends on two other components, as already indicated above: stakeholder participation and the quality and adequacy of the various interventions as prescribed by the MP.

The key stakeholders on which the success of the HPMP depends are importers, technocrats (academics, researchers), educators, regulators (NOU, BURS), enforcers (law enforcement agents) and users (final and industrial). In particular, four stakeholder Cs – cognisance (awareness), cooperation (buy-in), capacitation (enablement) and compliance – are required for success. The failure of any of these imperatives jeopardises the achievement of the HCFC-22 importation, consumption and emission reduction milestones that the HPMP targets.

The key drivers of the implementation process are the financial mechanisms and the regulatory and non-regulatory interventions. These are assumed to be of equal importance to the success of the country's HPMP, with any inadequacy in any one area detracting from the overall success of the HPMP. By financing mechanisms the researcher means the timing and regularity of funding allocations from the responsible UNEP agency. Botswana is an Article 5 country and requires this funding model in order to meet its MP obligations. By regulatory interventions the researcher means a comprehensive legislative framework which addresses all aspects of the supply chains of both HCFC-22 and other ODSs, as well as the equipment that depends on these. Appropriate sanctions for violations form a necessary part of that legislative framework, to ensure stakeholder compliance. The non-regulatory category of intervention addresses predominantly the cognisance, cooperation and capacitation imperatives of stakeholder involvement through training, information dissemination and technology transfer.

8.5.2 Contribution to the existing body of knowledge

This study is set against the backdrop of most others concentrating on the chemical and physical dynamics of ODS emissions, their atmospheric impact on the ozone layer and the resulting climate change and global warming effects. Additionally, most such studies thus far have concentrated on developed countries, the chief assumption being that these countries are the major drivers of ODS emissions. Apparently, the first such study to be carried out in Southern Africa was in 2018, by two Zimbabwean scientists (Manatsa and Mukwada, 2019). Its focus was on the effects of ozone on rainfall and temperatures in SA (Manatsa and Mukwada, 2019). The first novel contribution of this researcher's study is its focus on the human interventions (in the form of Botswana's HPMP) to reduce ODS emissions in a developing country in Southern Africa. This represents a shift of attention in research studies from the atmospheric and environmental effects of ozone depletion, to the various dimensions of positive and negative human activity driving the same.

Predominantly, the phase out of HCFC-22 has been highlighted in the literature. Be that as it may, this has been mostly theoretical. The second important contribution is that this study is one of the few studies that are actually based on empirical data. Thirdly, this study helped to debunk a number of myths, especially as regards the success of the MP and its various amendments to reducing HCFC-22 consumption and its impact. The study showed that quite clearly, HCFC-22 consumption could still be higher than claimed, or conversely, that the effectiveness of the MP might be overstated. This would mean a lot more work might still need to actually be done, especially in developing countries where the legal, administrative, logistical and enforcement infrastructure and arrangements still leave a lot to be desired.

8.5.3 Contribution to practice

There are many stakeholders practically involved in the fight against ozone depletion and its numerous adverse effects. These include importers, technocrats, educators, regulators, enforcers and users. This suggests the need for a systems approach to the ozone depletion fight. From a practical standpoint, this study highlighted the critical importance of a holistic, cross-sectoral, supply chain-wide approach at national level to the fight against ozone depletion. There are two subdimensions to this, and the study brought these out. One is the stakeholder dimension, the other is the interventional dimension. From a stakeholder point of view, the study highlighted the importance of stakeholder awareness, buy-in, capacitation and enablement. Overall HPMP success cannot and does not depend on one or other stakeholder but on all of them rightfully playing their respective roles. By the same token, from an interventional perspective, HPMP success also depends on ensuring studious adherence to and execution of the regulatory, non-regulatory and financial interventions. It is inconceivable that generous funding could produce positive results if the regulatory framework, for example, were lax or deficient, or if the various non-regulatory measures were not in place, and vice-versa.

Another practical contribution of this study should be the closure of the gaps in Botswana in terms of its fulfilment of its MP commitments. These were specifically identified and noted at the 15th meeting of the signatories to the MP Decision XV/31 and the 65th meeting on Decision XXV/15. Logically, these gaps could only be remedied if their causes were known, and this study has helped pinpoint those.

Currently, most of the Montreal treaty parties have made significant strides in the HCFC-22 phase-out plans, since they are more concerned with compliance as opposed to effectiveness, which encompasses the overall evaluation of the successful environmental goals (Knutson *et al.,* 2015). The effectiveness of the Montreal treaty is evaluated by reference to levels of stakeholder commitment as well as the economic, social and environmental impacts.

8.5.4 Contribution to policy

This study has emerged against the backdrop of policy making not being guided by any apparent empirical evidence emanating from scientific research. This motivated research to develop an INTHPO framework that seeks to plug the gaps in the present HPMP and thus enhance the effectiveness of efforts to phase out and eventually eliminate the consumption and emission of HCFC-22 and other ODSs. The first significant contribution of this study to policy, therefore, is to propose an empirically informed framework not only aligned on a macro-level to the MP, but also shaped on a micro-level by the unique idiosyncrasies, circumstances, realities and challenges of Botswana. Government and development partner institutions can use this framework in their policy crafting and advocacy, public awareness raising and mitigation of the effects of HCFC-22 and other ODSs. The same framework focuses attention on the fundamentals of implementation per se, as explained in section 8.4.4, namely, the people (stakeholders), the process (supply chain) and the enablers (financial mechanisms, regulatory structure and non-regulatory initiatives). The research approach is intended not to dismiss or discredit the current HCFC-22 phase-out policy and plan as ineffective but to augment them and offer holistic, cross-cutting suggestions for their enhancement. It is the researcher's proposition that an effective policy and plan for HCFC-22 phase out must, in addition to current efforts address, in totality, the stakeholder buy-in, resourcing and regulatory and non-regulatory issues involved in the entire supply chain.

8.6 Areas for further research

This study focused on the evaluation of the phase-out management systems of an ODS, HCFC-22, and its environmental and socioeconomic implications in Botswana. It evaluated the levels of awareness and product knowledge of service stakeholders, the level of compliance of Botswana to the MP resolutions, as well as the achieved milestones and impacts of HCFC-22 phase-out. SA's and Botswana's HCFC-22 phase-out management strategies and implementation based on the MP resolutions were also compared. However, there are other important areas that need further research. These include the following:

- Overall, there are significant differences on the level of product knowledge and awareness of the HCFC-22 phase-out between stakeholders; hence, further in-depth analysis is required to explore and understand these relationships. There is also a need to investigate the methods used to disseminate the information among stakeholders.

- This study focused mainly on the quantity of HCFC-22 imported into Botswana for servicing the already existing equipment. There is consequently a need to further investigate the amount of HCFC-22 in new equipment imported from other countries into Botswana, as well as a need to calculate the emission of HCFC-22 and its substitutes in Botswana.

- The study revealed the country's efforts to promote the adoption of alternative technologies. This issue requires further research so that the country will come up with the best alternatives.

- This study did not look at the phase down of HCFC-22 substitutes and their effects on climate change; hence, further research is needed to establish the relationship between these issues.

- This study revealed that there are no disposal facilities for ODSs in Botswana and thus further research is needed on the management of the disposal of HCFC-22 and other ODSs.

- Though it was not the objective of this study, it will be interesting to trace what happens to the HCFCs when they eventually get deposited on surfaces like water and soil from the air and investigate their environmental impacts.

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APPENDICES

APPENDIX A: QUESTIONNAIRES

A1: QUESTIONNAIRE FOR THE MINISTRY OF ENVIRONMENT/DEPARTMENT OF METEOROLOGICAL SERVICES EMPLOYEES

Dear Respondent

RE: REQUEST TO COMPLETE AN ACADEMIC QUESTIONNAIRE

My name is Bongayi Kudoma a PhD student at UNISA researching on the topic entitled "**An evaluation of the phase out management systems of an Ozone depleting substance HCFC-22 and its environmental implications in Botswana**. This research is an original contribution to the wider academic body of knowledge, and to be used for academic purposes only. You have been identified and selected as a respondent to contribute towards the completion of this questionnaire. Your identity shall be kept anonymous and your contributions shall be treated with the strictness of confidentiality, and to be used entirely for academic purposes only. Participation in this survey is voluntary and you can withdraw from the study without any obligations, but you are encouraged to take part and answer all questions to the best of your ability.

SECTION A: DEMOGRAPHIC INFORMATION

1.1 Years of service provision ....

1.2 Management/Non-management ....

1.3 Level of education ....

SECTION B: HCFC-22 PRODUCT KNOWLEDGE AND PHASE OUT AWARENESS

2.1 HCFC-22 PRODUCT KNOWLEDGE

Please tick the box that is most appropriate for your response ranging from strongly agree to strongly disagree, for the following set of statements.

Strongly agree	Somewhat agree	Agree	Neutral	Disagree	Somewhat disagree	Strongly disagree
+3	+2	+1	0	-1	-2	-3

	+3	+2	+1	0	-1	-2	-3
HCFC-22 is the main refrigerant currently in use.							
HCFC-22 is used in chillers.							
HCFC-22 is used in cold storage.							
HCFC-22 is used for medical purposes.							
HCFC-22 is used as blowing agent for certain applications.							
HCFC-22 is used in fire-fighting equipment.							
Air conditioners in Botswana are all using HCFC-22.							
HCFC-22 is used in retail food refrigeration equipment.							
HCFC-22 is used in food preservation.							
HCFC-22 is used in car air conditioners.							
In transit food vehicles use HCFC-22 for cooling.							

2.2 HCFC-22 PHASE OUT AWARENESS

Strongly agree	Somewhat agree	Agree	Neutral	Disagree	Somewhat disagree	Strongly disagree
+3	+2	+1	0	-1	-2	-3

	+3	+2	+1	0	-1	-2	-3
There are no current plans in Botswana to phase out HCFC-22.							
There are no HCFC-22 import restrictions in Botswana.							
There are no strict licensing requirements of importers of HCFC-22 in Botswana.							
There are no annual quota system requirements for importers and distributors of HCFC-22 in Botswana.							
Botswana is mandated to phase out the importation of HCFC-22.							
Botswana has no Hydrochlorofluorocarbons Phase-out Management Plan (HPMP).							
Air conditioning equipment using HCFC-22 is not restricted from entering Botswana.							
Refrigeration equipment using HCFC-22 for domestic purposes is not restricted by import quotas.							
There are no legislative restrictions on the importation of HCFC-22 in Botswana.							
The no legal restrictions for importation of HCFC-22 equipment in Botswana.							

SECTION C: MANAGEMENT OF HCFC-22 PHASE OUT

Kindly answer in depth the following questions as appropriate and tick the box that is most appropriate for your response.

1. Who is responsible for HCFC-22 phase out and monitoring activities?

----

2. Is there a RAC (Refrigeration Air Conditioning) association in Botswana?

☐ Yes ☐ No ☐ Not aware

3. If yes, who are the members of the association?

----

4. Where are the waste disposal centres for refrigerants from RAC equipment?

----

5. What measures have been put in place to prevent illegal trade of HCFC-22?

----

6. What milestones have Botswana attained on the phase out of HCFC-22 pursuant to the Montreal Protocol?

----

7. What are the major challenges for Botswana with regard to HCFC-22 phase out?

----

8. What are the initiatives done by the Department of Meteorological Services to facilitate effective phase out of HCFC-22?

----

9. Are you familiar with the National Meteorological Service Act of 2014 and the Ozone Depleting Substances regulation 2014?

☐ Yes ☐ No

10. If yes, to what extend do you comply with the legislations?

☐ Low extend ☐ Moderate extend ☐ High extend

11. Are you familiar with the Botswana Hydrochlorofluorocarbons Phase-out Management Plan (HPMP)?

☐ Yes ☐ No

12. To what extend does the Department of Meteorological Services implement and comply with the Botswana HPMP, National Meteorological Act of 2014 and ODS regulation of 2014?
Please tick the box that is most appropriate for your response.

Strong positive compliance	**Moderate positive compliance**	**Minor positive compliance**	**No compliance**	**Minor negative compliance**	**Moderate negative compliance**	**Strong negative compliance**
+3	**+2**	**+1**	**0**	**-1**	**-2**	**-3**

	+3	**+2**	**+1**	**0**	**-1**	**-2**	**-3**
Issue of permits to importers of HCFC-22.							
Issue of permits to technicians in servicing and installation of ODS equipment.							
Suspension of import permit if the permit holder fail to comply							
Control of HCFC-22 imports/quota.							
Training of technicians in servicing sector.							
Training of customs officers.							
Keep record of permits issued							
Monitor business of licensed importers.							
Record HCFC-22 imported.							
Receive annual HCFC-22 imports reports by the 15th January.							

Monitor transportation of HCFC-22.							
Publish in the Government Gazette list of ODS before 31 December every year.							
Raising awareness/ campaign of HCFC-22 phase out.							
Enforcement of the legislation.							
Monitoring of the refrigeration association.							
Monitor disposal of HCFC-22.							
Promotion of adoption of alternatives.							
Retrofit and recovery activities.							
Provision of retrofit service tool kit to end-users.							
Use of the refrigerant identifier at entry ports.							

13. What are the impacts of phasing out HCFC-22 refrigerant?
Please tick the box that is most appropriate for your response.

Very strong positive impact	**Strong positive impact**	**Moderate positive impact**	**Minor positive impact**	**No impact**	**Minor negative impact**	**Moderate negative impact**	**Strong negative impact**	**Very strong negative impact**
+4	**+3**	**+2**	**+1**	**0**	**-1**	**-2**	**-3**	**-4**

a) Social impacts

	+4	**+3**	**+2**	**+1**	**0**	**-1**	**-2**	**-3**	**-4**
Employment									
Education and training.									
Community awareness									
Health and physical wellbeing									
Replacement cost									

b) Economic impacts

	+4	**+3**	**+2**	**+1**	**0**	**-1**	**-2**	**-3**	**-4**
Substitutes of HCFC-22 are expensive									
Demand for HCFC-22 is high									
Reduction of HCFC-22 supplies									
High cost of servicing HCFC-22 equipment									
Low prices for prices of HCFC-22									
Difficult to invest in new technology before complete phase out of HCFC-22	`								
Technological transition cost of the phase out of HCFC-22 is high.									
Technological change will render the old HCFC-22 equipment absolute									
High potential illegal trade									

c) Environmental impacts

	+4	**+3**	**+2**	**+1**	**0**	**-1**	**-2**	**-3**	**-4**
Proposed HCFC-22 substitutes contribute to global warming.									
Substitutes of HCFC-22 contribute to climate change.									
Phasing out of HCFC-22 reduce ozone depletion									
High risk of HCFC-22 venting in air through dumped equipment.									
Reduce emission of HCFC-22									

Phasing out generates waste through HCFC-22 equipment dumbs.									
Reduce global warming effect of HCFC-22									
The employment of new technologies brings about a reduction in CO_2 emissions.									
HCFC-22 phase out benefit ozone layer protection.									
Phase out of HCFC-22 increase energy saving									
Potential dumpsite for unwanted HCFC-22 equipment through illegal entry.									
HCFC-22 have a lower energy efficiency ratio (EER)									

End of the questionnaire

Thank you for your time

A2: QUESTIONNAIRE FOR THE HCFC-22 RETAIL CONSUMER COMPANIES/IMPORTERS

Dear Respondent

RE: REQUEST TO COMPLETE AN ACADEMIC QUESTIONNAIRE

My name is Bongayi Kudoma a PhD student at UNISA researching on the topic entitled "**An evaluation of the phase out management systems of an Ozone depleting substance HCFC-22 and its environmental implications in Botswana**. This research is an original contribution to the wider academic body of knowledge, and to be used for academic purposes only. You have been identified and selected as a respondent to contribute towards the completion of this questionnaire. Your identity shall be kept anonymous and your contributions shall be treated with the strictness of confidentiality, and to be used entirely for academic purposes only. Participation in this survey is voluntary and you can withdraw from the study without any obligations, but you are encouraged to take part and answer all questions to the best of your ability.

SECTION A: DEMOGRAPHIC INFORMATION

1.4 Years of service provision ....
1.5 Management/Non-management ....
1.6 Level of education ....

SECTION B: HCFC-22 PRODUCT KNOWLEDGE AND PHASE OUT AWARENESS

2.1 HCFC-22 PRODUCT KNOWLEDGE

Please tick the box that is most appropriate for your response ranging from strongly agree to strongly disagree, for the following set of statements.

Strongly agree	**Somewhat agree**	**Agree**	**Neutral**	**Disagree**	**Somewhat disagree**	**Strongly disagree**
+3	**+2**	**+1**	**0**	**-1**	**-2**	**-3**

	+3	**+2**	**+1**	**0**	**-1**	**-2**	**-3**
HCFC-22 is the main refrigerant currently in use.							
HCFC-22 is used in chillers.							
HCFC-22 is used in cold storage.							
HCFC-22 is used for medical purposes.							
HCFC-22 is used as blowing agent for certain applications.							
HCFC-22 is used in fire-fighting equipment.							
Air conditioners in Botswana are all using HCFC-22.							
HCFC-22 is used in retail food refrigeration equipment.							
HCFC-22 is used in food preservation.							
HCFC-22 is used in car air conditioners.							
In transit food vehicles use HCFC-22 for cooling.							

2.2 HCFC-22 PHASE OUT AWARENESS

Strongly agree	Somewhat agree	Agree	Neutral	Disagree	Somewhat disagree	Strongly disagree
+3	**+2**	**+1**	**0**	**-1**	**-2**	**-3**

	+3	+2	+1	0	-1	-2	-3
There are no current plans in Botswana to phase out HCFC-22.							
There are no HCFC-22 import restrictions in Botswana.							
There are no strict licensing requirements of importers of HCFC-22 in Botswana.							
There are no annual quota system requirements for importers and distributors of HCFC-22 in Botswana.							
Botswana is mandated to phase out the importation of HCFC-22.							
Botswana has no Hydrochlorofluorocarbons Phase-out Management Plan (HPMP).							
Air conditioning equipment using HCFC-22 is not restricted from entering Botswana.							
Refrigeration equipment using HCFC-22 for domestic purposes is not restricted by import quotas.							
There are no legislative restrictions on the importation of HCFC-22 in Botswana.							
The no legal restrictions for importation of HCFC-22 equipment in Botswana.							

SECTION C: MANAGEMENT OF HCFC-22 PHASE OUT

Kindly answer in depth the following questions as appropriate and tick the box that is most appropriate for your response.

1. Where do you import the equipment with HCFC-22 refrigerant from?

----

2. Which border post/port of entry do you use to import equipment with HCFC-22?

----

3. List other companies that import/export HCFC-22 in Botswana

----

----

4. Where do you report HCFC-22 annual trade and consumption date?

----

5 Are you familiar with the National Meteorological Service Act of 2014 and the Ozone Depleting Substances regulation of 2014?

☐ Yes ☐ No

6 If yes, to what extend do you comply with the legislations?

☐ Low Extend ☐ Moderate Extend ☐ High Extend

7 Are you familiar with the Botswana Hydrochlorofluorocarbons Phase-out Management Plan (HPMP?)

☐ Yes ☐ No

8 The regulation requires that importers should keep a record of names and addresses of entities to whom the ODS has been supplied. Does your company keep records of names and addresses of your customers?

☐ Yes ☐ No

9 The regulation requires importers to cause the person who buys controlled substance to sign a declaration form as set of schedule for ODS regulation. Do they sign the declaration form?

☐ Yes ☐ No

10 Do you discuss the HCFC-22 phase out with your customers?

☐ Yes ☐ No

11 Is the shrinkage/reduction of import of HCFC-22 implemented by your company?

☐ Yes ☐ No

What are your substitutes for HCFC-22?

----

12 What is the price trend of HCFC-22 since the phase out started?

☐ Raising ☐ Stagnant ☐ Decreasing ☐ Others Specify ---------------------

13 Do you carry out refrigerant leakage test to HCFC-22 equipment before selling them?

☐ Yes ☐ No

14 Does your company have technicians who service air-conditions or refrigerators?

☐ Yes ☐ No

15 If yes, do they have permits that allow them to service or repair HCFC-22 equipment?

☐ Yes ☐ No

16 Where do you dispose equipment with HCFC-22 refrigerants?

----

17 What initiatives are done by your company to facilitate HCFC- 22 phase out?

----

18 What are the challenges your company is facing concerning the phase out of HCFC-22?

----

19 What are the impacts of phasing out HCFC-22 refrigerant?
Please tick the box that is most appropriate for your response.

Very strong positive impact	Strong positive impact	Moderate positive impact	Minor positive impact	No impact	Minor negative impact	Moderate negative impact	Strong negative impact	Very strong negative impact
+4	**+3**	**+2**	**+1**	**0**	**-1**	**-2**	**-3**	**-4**

d) Social impacts

	+4	+3	+2	+1	0	-1	-2	-3	-4
Employment									
Education and training.									
Community awareness									
Health and physical wellbeing									
Replacement cost									

e) Economic impacts

	+4	+3	+2	+1	0	-1	-2	-3	-4
Substitutes of HCFC-22 are expensive									
Demand for HCFC-22 is high									
Reduction of HCFC-22 supplies									
High cost of servicing HCFC-22 equipment									
Low prices for prices of HCFC-22									
Difficult to invest in new technology before complete phase out of HCFC-22	`								
Technological transition cost of the phase out of HCFC-22 is high.									
Technological change will render the old HCFC-22 equipment absolute									
High potential illegal trade									

f) Environmental impacts

	+4	+3	+2	+1	0	-1	-2	-3	-4
Proposed HCFC-22 substitutes contribute to global warming.									
Substitutes of HCFC-22 contribute to climate change.									
Phasing out of HCFC-22 reduce ozone depletion									
High risk of HCFC-22 venting in air through dumped equipment.									
Reduce emission of HCFC-22									
Phasing out generates waste through HCFC-22 equipment dumbs.									
Reduce global warming effect of HCFC-22									
The employment of new technologies brings about a reduction in CO_2 emissions.									
HCFC-22 phase out benefit ozone layer protection.									

Phase out of HCFC-22 increase energy saving									
Potential dumpsite for unwanted HCFC-22 equipment through illegal entry.									

End of the questionnaire

Thank you for your time

A3: QUESTIONNAIRE FOR THE CUSTOMS OFFICERS

Dear Respondent

RE: REQUEST TO COMPLETE AN ACADEMIC QUESTIONNAIRE

My name is Bongayi Kudoma a PhD student at UNISA researching on the topic entitled "**An evaluation of the phase out management systems of an Ozone depleting substance HCFC-22 and its environmental implications in Botswana**. This research is an original contribution to the wider academic body of knowledge, and to be used for academic purposes only. You have been identified and selected as a respondent to contribute towards the completion of this questionnaire. Your identity shall be kept anonymous and your contributions shall be treated with the strictness of confidentiality, and to be used entirely for academic purposes only. Participation in this survey is voluntary and you can withdraw from the study without any obligations, but you are encouraged to take part and answer all questions to the best of your ability.

SECTION A: DEMOGRAPHIC INFORMATION

1.7 Years of service provision ....

1.8 Management/Non-management ....

1.9 Level of education ....

SECTION B: HCFC-22 PRODUCT KNOWLEDGE AND PHASE OUT AWARENESS

2.1 HCFC-22 PRODUCT KNOWLEDGE

Please tick the box that is most appropriate for your response ranging from strongly agree to strongly disagree, for the following set of statements.

Strongly agree	Somewhat agree	Agree	Neutral	Disagree	Somewhat disagree	Strongly disagree
+3	+2	+1	0	-1	-2	-3

	+3	+2	+1	0	-1	-2	-3
HCFC-22 is the main refrigerant currently in use.							
HCFC-22 is used in chillers.							
HCFC-22 is used in cold storage.							
HCFC-22 is used for medical purposes.							
HCFC-22 is used as blowing agent for certain applications.							
HCFC-22 is used in fire-fighting equipment.							
Air conditioners in Botswana are all using HCFC-22.							
HCFC-22 is used in retail food refrigeration equipment.							
HCFC-22 is used in food preservation.							
HCFC-22 is used in car air conditioners.							
In transit food vehicles use HCFC-22 for cooling.							

2.2 HCFC-22 PHASE OUT AWARENESS

Strongly agree	Somewhat agree	Agree	Neutral	Disagree	Somewhat disagree	Strongly disagree
+3	+2	+1	0	-1	-2	-3

	+3	+2	+1	0	-1	-2	-3
There are no current plans in Botswana to phase out HCFC-22.							
There are no HCFC-22 import restrictions in Botswana.							
There are no strict licensing requirements of importers of HCFC-22 in Botswana.							
There are no annual quota system requirements for importers and distributors of HCFC-22 in Botswana.							
Botswana is mandated to phase out the importation of HCFC-22.							
Botswana has no Hydrochlorofluorocarbons Phase-out Management Plan (HPMP).							
Air conditioning equipment using HCFC-22 is not restricted from entering Botswana.							
Refrigeration equipment using HCFC-22 for domestic purposes is not restricted by import quotas.							
There are no legislative restrictions on the importation of HCFC-22 in Botswana.							
The no legal restrictions for importation of HCFC-22 equipment in Botswana.							

SECTION C: MANAGEMENT OF HCFC-22 PHASE OUT

Kindly answer in depth the following questions as appropriate and tick the box that is most appropriate for your response.

1 Are you familiar with the National Meteorological Service Act of 2014 and the Ozone Depleting Substances regulation of 2014?

☐ Yes ☐ No

2 If yes, to what extend do you comply with the legislations?

☐ Low Extend ☐ Moderate Extend ☐ High Extend

3 Are you familiar with the Botswana Hydrochlorofluorocarbons Phase-out Management Plan (HPMP?)

☐ Yes ☐ No

4 Have you received training in handling Ozone Depleting Substances?

☐ Yes ☐ No

5 If yes, when were you trained?

☐ 2010-2011 ☐ 2012-2013 ☐ 2014-2015 ☐ 2016-2017

6 Do you have a list of companies with ODS import permit that import HCFC-22 into Botswana?

☐ Yes ☐ No

7 Do you have quota for companies that import HCFC-22 refrigerant into Botswana?

☐ Yes ☐ No

8 Do you use customs codes to track imports of ODS?

☐ Yes ☐ No

9 How do you monitor the HCFC-22 and equipment imported into Botswana by sellers/distributors/importers?

----

10 Do you have gas identifiers that detect different types of refrigerants?

☐ Yes ☐ No

11 What measures have been put in place to prevent illegal trade of HCFC-22?

----

12 Who is responsible for coordinating HCFC-22 phase out and monitoring activities?

----

13 What are the initiatives being done by BURS to facilitate effective phase out of HCFC-22?

----

14 What challenges do you encounter regarding importation of HCFC-22 and other ozone depleting substances?

----

20 What are the impacts of phasing out HCFC-22 refrigerant?
Please tick the box that is most appropriate for your response.

Very strong positive impact	Strong positive impact	Moderate positive impact	Minor positive impact	No impact	Minor negative impact	Moderate negative impact	Strong negative impact	Very strong negative impact
+4	+3	+2	+1	0	-1	-2	-3	-4

g) Social impacts

	+4	+3	+2	+1	0	-1	-2	-3	-4
Employment									
Education and training.									
Community awareness									
Health and physical wellbeing									
Replacement cost									

h) Economic impacts

	+4	+3	+2	+1	0	-1	-2	-3	-4
Substitutes of HCFC-22 are expensive									
Demand for HCFC-22 is high									
Reduction of HCFC-22 supplies									
High cost of servicing HCFC-22 equipment									
Low prices for prices of HCFC-22									
Difficult to invest in new technology before complete phase out of HCFC-22	`								
Technological transition cost of the phase out of HCFC-22 is high.									
Technological change will render the old HCFC-22 equipment absolute									
High potential illegal trade									

i) Environmental impacts

	+4	+3	+2	+1	0	-1	-2	-3	-4
Proposed HCFC-22 substitutes contribute to global warming.									
Substitutes of HCFC-22 contribute to climate change.									
Phasing out of HCFC-22 reduce ozone depletion									
High risk of HCFC-22 venting in air through dumped equipment.									
Reduce emission of HCFC-22									
Phasing out generates waste through HCFC-22 equipment dumbs.									
Reduce global warming effect of HCFC-22									
The employment of new technologies brings about a reduction in CO_2 emissions.									
HCFC-22 phase out benefit ozone layer protection.									
Phase out of HCFC-22 increase energy saving									
Potential dumpsite for unwanted HCFC-22 equipment through illegal entry.									
HCFC-22 have a lower Energy Efficiency Ratio (EER)									

End of the questionnaire **Thank you for your time**

A4: QUESTIONNAIRE FOR THE HCFC-22 PRODUCT AND EQUIPMENT CONSUMERS/ END USER CONSUMERS.

Dear Respondent

<u>RE: REQUEST TO COMPLETE AN ACADEMIC QUESTIONNAIRE</u>

My name is Bongayi Kudoma a PhD student at UNISA researching on the topic entitled "**An evaluation of the phase-out management systems of an Ozone depleting substance HCFC-22 and its environmental implications in Botswana**. This research is an original contribution to the wider academic body of knowledge, and to be used for academic purposes only. You have been identified and selected as a respondent to contribute towards the completion of this questionnaire. Your identity shall be kept anonymous and your contributions shall be treated with the strictness of confidentiality, and to be used entirely for academic purposes only. Participation in this survey is voluntary and you can withdraw from the study without any obligations, but you are encouraged to take part and answer all questions to the best of your ability.

SECTION A: DEMOGRAPHIC INFORMATION

1.10 Years of service provision ....
1.11 Management/Non-management ....
1.12 Level of education ....

SECTION B: HCFC-22 PRODUCT KNOWLEDGE AND PHASE-OUT AWARENESS

2.1 HCFC-22 PRODUCT KNOWLEDGE

Please tick the box that is most appropriate for your response ranging from strongly agree to strongly disagree, for the following set of statements.

Strongly agree	Somewhat agree	Agree	Neutral	Disagree	Somewhat disagree	Strongly disagree
+3	+2	+1	0	-1	-2	-3

	+3	+2	+1	0	-1	-2	-3
HCFC-22 is the main refrigerant currently in use.							
HCFC-22 is used in chillers.							
HCFC-22 is used in cold storage.							
HCFC-22 is used for medical purposes.							
HCFC-22 is used as blowing agent for certain applications.							
HCFC-22 is used in fire-fighting equipment.							
Air conditioners in Botswana are all using HCFC-22.							
HCFC-22 is used in retail food refrigeration equipment.							
HCFC-22 is used in food preservation.							
HCFC-22 is used in car air conditioners.							
In transit food vehicles use HCFC-22 for cooling.							

2.2 HCFC-22 PHASE-OUT AWARENESS

Strongly agree	Somewhat agree	Agree	Neutral	Disagree	Somewhat disagree	Strongly disagree
+3	**+2**	**+1**	**0**	**-1**	**-2**	**-3**

	+3	+2	+1	0	-1	-2	-3
There are no current plans in Botswana to phase-out HCFC-22.							
There are no HCFC-22 import restrictions in Botswana.							
There are no strict licensing requirements of importers of HCFC-22 in Botswana.							
There are no annual quota system requirements for importers and distributors of HCFC-22 in Botswana.							
Botswana is mandated to phase out the importation of HCFC-22.							
Botswana has no Hydrochlorofluorocarbons Phase-out Management Plan (HPMP).							
Air conditioning equipment using HCFC-22 is not restricted from entering Botswana.							
Refrigeration equipment using HCFC-22 for domestic purposes is not restricted by import quotas.							
There are no legislative restrictions on the importation of HCFC-22 in Botswana.							
The no legal restrictions for importation of HCFC-22 equipment in Botswana.							

SECTION C: MANAGEMENT OF HCFC-22 PHASE OUT

Kindly answer in depth the following questions as appropriate and tick the box that is most appropriate for your response.

1 Are you familiar with the National Meteorological Service Act of 2014 and the Ozone Depleting Substances regulation of 2014?

☐ Yes ☐ No

2 If yes, to what extend do you comply with the legislations?

☐ Low Extend ☐ Moderate Extend ☐ High Extend

3 Are you familiar with the Botswana Hydrochlorofluorocarbons Phase-out Management Plan (HPMP?)

☐ Yes ☐ No

4 What is the price trend of HCFC-22 equipment is since the phase out started?

☐ Increasing ☐ Stagnant ☐ Decreasing ☐ Others Specify

5 Do you discuss HCFC-22 phase-out with your supplier?

☐ Yes ☐ No

6 When you buy equipment with HCFC- 22 do you sign any declaration form?

☐ Yes ☐ No

7 What is the available alternative for HCFC-22?

----

8 What are the challenges of switching to HCFC-22 alternatives?

----

9 Do you have technicians who service air-conditions or refrigerators?

☐ Yes ☐ No

10 If yes, do they have permits that allow them to service or repair HCFC-22 equipment?

☐ Yes ☐ No

11 Where do you dispose the equipment with HCFC-22 refrigerant?

End of the questionnaire

Thank you for your time

APPENDIX B: INTERVIEW GUIDES

Interview guide for the National Ozone Officer

1 What are Botswana's annual data for importation/ consumption of HCFC 22 for the period 2009 to 2017?
2 In the light of Article 4B of MP does Botswana have a licensing system for importing and exporting ozone depleting substances?
3 How do you collect HCFC-22 imports/exports data from importer and BURS?
4 What are the yearly quota allocations for individual companies with permits to import HCFC-22?
5 Is there a RAC (Refrigeration Air Conditioning) association in Botswana?
6 If yes, that is the name of the association and how does it operate?
7 Does the public have access to the Botswana HPMP, the National Meteorological Act of 2014 and the ODS regulations of 2014?
8 Are they policies that restrict importation of HCFC-22 from countries Botswana is importing from?
9 Are there retrofit and recycling/recovery centres in Botswana?
10 Are there waste disposal centres for refrigerants from RAC equipment in Botswana?
11 What measures have been put in place to prevent illegal trade of HCFC-22?
12 How many refrigerant identifiers are there in Botswana?
13 What are the major challenges your office encounter with regard to HCFC-22 phase out?
14 How does Botswana manage the phase-out of HCFC-22?

Interview guide for the principal customs officer from BURS

1 How many customs officers received training in handling ozone depleting substances?
2 Do you have a list of companies with ODS import permit that import HCFC-22 into Botswana?
3 Do you have quota for companies that import HCFC-22 refrigerant into Botswana?
4 Do you use customs codes to track imports of ODS?
5 How do you monitor the HCFC-22 and equipment imported into Botswana by sellers/distributors/ importers?
6 Do you have gas identifiers that detect different types of refrigerants?
7 Who is responsible for coordinating HCFC-22 phase out and monitoring activities?
8 What measures have been put in place to prevent illegal trade of HCFC-22?

9 What challenges did you encounter regarding importation of HCFC-22 and other Ozone depleting Substances?

10 What are the initiatives being done by BURS to facilitate effective phase out of HCFC-22?

Interview guide for representatives from companies

1 What is your annual consumption of HCFC-22 for the period 2015-2017?

2 What is your quarterly consumption of HCFC-22 for the period 2017?

3 When do you report HCFC-22 consumption data to the NOO?

4 Is the shrinkage/reduction of import of HCFC-22 implemented by your company?

5 What is your annual quota for HCFC-22 consumption?

6 Does your organization carry out HCFC-22 phase out awareness programs?

7 What are the challenges of phasing out HCFC-22 your business is experiencing?

8 Where do you dispose equipment with HCFC-22 refrigerants?

9 What initiatives are done by your company to facilitate HCFC- 22 phase out?

APPENDIX C: HCFC-22 MEASUREMENTS AND OBSERVATION SHEETS

C1: HCFC-22 MEASUREMENT SHEET FOR IMPORTERS/COMPANIES

Name of Company: ____

Year	Quantity imported Jan-March	Quantity imported April-June	Quantity imported July-Sept	Quantity imported Oct-Dec
2015				
2016				
2017				

C2: HCFC-22 MEASUREMENT SHEET FOR DMS SERVICES

Quantity imported 2009	**Quantity imported 2010**	**Quantity imported 2011**	**Quantity imported 2012**	**Quantity imported 2013**	**Quantity imported 2014**	**Quantity imported 2015**	**Quantity imported 2016**	**Quantity imported 2017**
1								

C3: HCFC-22 MEASUREMENT SHEET FOR CUSTOMS

Country of origin	**Quantity imported 2013**	**Quantity imported 2014**	**Quantity imported 2015**	**Quantity imported 2016**	**Quantity imported 2017**
South Africa					
China					
Others					

C4: OBSERVATION SHEET

PLACE OF OBSERVATION____

	1st Quarter Jan-March	2nd Quarter April-June	3rd Quarter July-Sept	4th Quarter Oct-Dec
DATE				
Presence of import permit. Yes/No				
Presence of ODS regulation. Yes/No				
Presence of fire emergency equipment accessible and visible. Yes/No				
Stacking and storage practice. Good/Poor				
HCFC-22 storage room. Secure/ insecure				
HCFC-22 storage room. Ventilated/not ventilated area				
Presence of leak detectors. Yes/No				
HCFC-22 packages sealed. Yes/No				
Storage area Properly labelled ODS warning signs. Yes/No				
Transportation of HCFC-22 -Use of designated vehicle/ -Use of any vehicle				
Existence of training/awareness programme on ODS offered to workers/ customers. Yes/No				
Presence ODS inspection Form Yes/No				
Exposure to HCFC-22 sunlight/hot surface. Yes/No				

APPENDIX D: RESEARCH PERMIT FROM THE MINISTRY OF ENVIRONMENT, WILDLIFE AND TOURISM

TELEPHONE: 3647900
TELEGRAMS: MEWT
TELEX:
TELEFAX: 3908076

REFERENCE: EWT 8/36/4 XXXVII (43)

REPUBLIC OF BOTSWANA

MINISTRY OF ENVIRONMENT,
WILDLIFE AND TOURISM
PRIVATE BAG BO 199
GABORONE
BOTSWANA

ALL CORRESPONDENCE MUST BE ADDRESSED TO
THE PERMANENT SECRETARY

13th October, 2016

Ms Bongayi Kudoma
Ba Isago University
Private Bag F238
Francistown

Tel: +267 71 442 531/ 73 235 979
Email: bmakova06@yahoo.com or 50519204@mylife.unisa.ac.za

APPLICATION FOR A RESEARCH PERMIT: "AN EVALUATION OF THE MANAGEMENT SYSTEMS OF AN OZONE DEPLETING SUBSTANCE HCFC-22 AND ITS ENVIRONMENTAL IMPLICATIONS IN BOTSWANA": EWT 8/36/4 XXXVII (42)

We are pleased to inform you that you are granted permission to conduct a research entitled: **"an evaluation of the management systems of an ozone depleting substance hcfc-22 and its environmental implications in Botswana."**

The research will be conducted at **Gaborone and Maun.**

This permit is valid for a period effective from the **1st January 2017 to 30th December 2018.**

This permit is granted subject to the following conditions:

1. Signing and submission of an Agreement between Government of Botswana and Independent Researchers.
2. Progress should be reported periodically to the **Department of Meteorological Services.**

Our mission: *To protect the environment; Conserve the country's renewable and natural resources; Derive value out of environment for the benefit of Botswana*

BOTSWANA

3. The permit does not give authority to enter premises, private establishments or protected areas. Permission for such entry should be negotiated with those concerned.

4. You conduct the study according to particulars furnished in the approved application taking into account the above conditions.

5. Failure to comply with any of the above conditions will result in the immediate cancellation of this permit.

6. The research team comprises of **Ms Igobe Malidza, Mr Edison Chaba and Ms Bongayi Kudoma.**

7. The applicant should ensure that the Government of Botswana is duly acknowledged.

8. Copies of videos/publications produced as a result of this project are directly deposited with the Office of the President, National Assembly, Ministry of Environment, Wildlife and Tourism, Department of National Museum and Monuments, Gaborone Botswana Tourism Organization, National Archives, National Library Service, and the University of Botswana Library.

Thank you.

Yours faithfully

Gaoakanye Tapeng

FOR/PERMANENT SECRETARY

cc: Director, Department of Meteorological Services
District Commissioner, Gaborone, Maun

MINISTRY OF ENVIRONMENT
WILDLIFE & TOURISM
PERMANENT SECRETARY
2016 -01- 13
RESEARCH & DEVELOPMENT UNIT
P/ BAG BO 199, GABORONE
TEL: +267 364 7600
FAX: +267 3914861

Our mission: *To protect the environment; Conserve the country's renewable and natural resources; Derive value out of environment for the benefit of Botswana*

BOTSWANA

APPENDIX E: PERMISSION LETTERS TO CONDUCT THE RESEARCH FROM STUDIED COMPANIES AND BURS

BOTSAND

Service at its excellent

BOTSAND INVESTMENTS (PTY) LTD
t/a *BOTSAND* Air Conditioners
PLOT 53/71 UNIT C1 & C2 COMMERCE PARK, GABORONE
P.O. BOX AD 98, ACG, GABORONE
Tel: 3500415 Fax: 3500399 email: botsand@btcmail.co.bw website: www.botsand.com

13th May 2017

To Whom It May Concern

RE: REQUEST TO COMPLETE ACADEMIC QUESTIONNAIRE

This letter serves to confirm that Ms. Bongayi Kudoma, a PhD student at UNISA requested from ourselves the above mentioned on the topic **"An Evaluation of the management systems of an Ozone depleting substance HCFC-22 and its environmental implications in Botswana".**

We are pleased to inform that permission was granted her, but with the understanding that our identity shall remain anonymous and our contributions shall also be treated with the strictness of confidentiality and will be used entirely for academic purposes ONLY.

In light of this therefore, the academic questionnaire answered by one of our company representative.

Hoping all suffices.

Regards.

E. Mburu Mrs
FOR/ Director

BOTSAND INVESTMENTS (PTY) LTD
P. O. BOX AD 98 ACG GABORONE
TEL: 3500415 FAX: 3500399
SUITE NO 55 POSTNET, TLOKWENG

METRACLARK

Refrigeration & Air-Conditioning Wholesale

Scotcool Refrigeration Wholesalers (Pty) Ltd
Reg No. Co.2003/5506
Vat No. C06452101112
Francistown
00 267 241 8230
Gaborone
002 67 391 0124

June 05, 2017.

Mrs. Bongayi Kudoma,

UNISA

SOUTH AFRICA.

Dear Madam,

REF: <u>PERMISSION TO CONDUCT ACADEMIC RESEARCH</u>

We are please to inform you that your request to conduct resesrch on the topic " An evaluation of the management systems of an Ozone Depleting Substance HCFC - 22 and its environmental implications in Botswana" is granted on conditions that the information obtained from Metraclark shall remain confidential.

We wish you all the best in carrying out your research.

Yours Faithfully

Operations Manager

Mbondenyi H. M

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MILEAGE AIR

THE BEST SERVICE YOU CAN TRUST

Ref: MA/Msc/09 **May 08, 2017**

Bongayi Kudoma
UNISA
Pretoria
South Africa

<u>RE: RESERCH</u>

We refer to your request to conduct research and we are pleased to allow you have access of information from our company regarding **The Management System of Ozone Depleting Substance HCF-22 and its Environmental Implications** in Botswana.

You are free to contact our employees for information required relevant to your research.

We trust this is in line with your requirements and you need further clarifications please do not hesitate to contact us.

Yours truly,

Grecian Missie
Projects Manager
For Mileage Air (Pty) Ltd.

MILEAGE AIR (PTY) LTD
P O BOX 2148
MOGODITSHANE BOTSWANA
PLOT 22125 G/WEST INDUSTRIAL
TEL: (+267) 3910246 FAX: (+267) 3910245
EMAIL:mileageair@yahoo.com

Plot 22125, Nyamambisa Street, Gaborone West Industrial, Gaborone
P.O. Box 2148, Mogoditshane, Botswana
Tel: 391 0246 Fax: 391 0245 E-mail: mileageair@yahoo.com

Mont

CATERING AND REFRIGERATION

9 MAY 2017

RE: RESEARCH COMPLETED FOR BONGAYI KUDUMO (UNIVERSITY OF SOUTH AFRICA)

This letter amplifies that;

1. Bongayi Kudoma, a student at University of South Africa approached us with a study on a topic titled **"AN EVALUATION OF THE MANAGEMENT SYSTEMS OF AN OZONE DEPLETING SUBSTANCE HCFC-22 AND ITS ENVIRONMENTAL IMPLICATIONS IN BOTSWANA".**
2. We answered the questionnaire and submitted information concerning our company and we hope this information will be kept confidential.
3. We wish Bongayi well in her studies.

Yours truly,

Ajay Varma

....

MANAGER

MONT CATERING & REFRIGERATION
(PTY) LTD
P.O. BOX AD 55AEG, KGALE VIEW POSTNET
PLOT 14459 G-WEST INDUSTRIAL
TEL:3900121 FAX: 3900126
email:mcr@mont.co.bw
VAT:CO6660501112

VBS IMPEX (PTY) LTD t/a

SILK AIR

PO BOX 602399, GABORONE, BOTSWANA

TEL/FAX: 3186903 CELL : 72238769

09-05-2017

RE: <u>REQUEST TO CONDUCT A RESERCH</u>

Ms Bongayi Kudoma

Ba Isago University

Private Bag F238, Francistown.

Permission has been given to MB Bongayi Kudoma to conduct a research on AN EVALUATION OF THE MANAGEMENT SYSTEMS OF AN OZONE DEPLETING SUBSTANCE HCFC-22 AND ITS ENVIRONMENTAL IMPLICATIONS IN BOTSWANA.

She has also been given permission to interview employees at Silk Air.

Thank you

Yours faithfully

SILK AIR
Tel/Fax: 3186903
Cell: 72238769
P.O. Box: 602399
Gaborone, Botswana

V B Nair

TecsaRecc
BROADHUST INDUSTRIAL
PLOT 5634 Nakedi Road UNIT 4
GABORONE
BOTSWANA
Tel 3919573
Fax 3919574
www.tecsareco.co.za
VAT No. C29008801113

Date 2017-05-15

TO WHO IT MAY CONCERN

RE : RESEARCH

Your request to conduct a research entitled ;AN EVALUATION OF THE MANAGEMENT SYSTEM OF AN OZONE DEPLETING SUBSTANCE- HCFC AND ITS ENVIROMENTAL IMPLICATION IN BOTSWANA in our organisation has been granted.

You are free to interview both employees and customers of the organisation. I hope the information that you are going to collect will be used for academic purpose only

YOURS FAITHFULLY

PETROS MPETE
(Branch Manager)

Armacell HENRY HC REFCO Embraco DORIN Danfoss ebmpapst Friga Systems BOCK

XL REFRIGERATION SUPPLY

XL REFRIGERATION SUPPLY (PTY) LTD
Plot 22121, Unit C
P. O. Box AD 98, ACG
Gaborone
Tel: 3933726
Fax: 3934493
E-mail: xlrefrigeration@brobemail.co.bw

22 May 2017

Ms Bongayi Kudoma
Ba Isago University
P Bag F238
Francistown

Dear Madam

RE: ACADEMIC RESEARCH

The management of XL REFRIGERATION SUPPLY has granted Ms B. Kudoma permission to conduct an academic research on: **An Evaluation of the Management Systems of An Ozone Depleting Substance HCFC-22 and its Environmental Implication in Botswana.**

She has been also allowed to interview our employees, customers and assessed our products.

Thank you.

Yours Faithfully

Zlateo Taric
Manging Director (For XL –Refrigeration Supply)

Wholesale in all Refrigeration Spare Parts, Air Conditioning-Residential & Commercial

J&G

REFRIGERATION SERVICES (Pty) Ltd.

Distributors of LG Air Conditioners
Stockiest of Air-conditioning and Refrigeration Spares

Plot 20580/1
Moshaneng Road
Block 3 Industrial
Gaborone

P.O Box 771
Gaborone,
Botswana

Tel : 3952035 / 3180461
Fax : 3956690
Cell : 71300985
Email : jg@info.bw
VAT# : C00205101111

Mrs Bonganyi Kudoma

UNISA

SOUTH AFRICA

26 June 2017

Dear Madam

RE: ACADEMIC RESEARCH ON HCFC-22 IN BOTSWANA

Permission granted to do your academic research on the topic entitled **"An Evaluation of the management system of an Ozone depleting substance HCFC-22 and its environmental implications in Botswana"** only on conditions that all the information obtained from this company will be kept confidential

We wish you all the best in your research

Yours faithfully

Kefeletswe Phaeno Koontsenyana
General Manager

J & G REFRIGERATION SERVICES (PTY) LTD
P.O. BOX 771 GABORONE
TEL: 3952035 FAX: 3956690
VAT # C00205101111

Ba Phil Supplies
" We supply only the best"

P O Box 10319
Tatitown, Francistown
Tel: 2403891 / Fax: 2401013
Cell: +267 73061438 / 71357070
Email: babogaemang@yahoo.com

100%
Customer
Satisfaction

01st September 2017

Mrs. Bongayi Kudoma

BA ISAGO University

P. Bag F238

Francistown

Dear Madam

RE: REQUEST FOR PERMISSION TO CONDUCT A RESEARCH STUDY

Reference is made to your letter dated 13 February 2017 on the subject matter above. Permission is hereby granted to you to contact a research on the topic: **An evaluation of the phase out management systems of an ozone depleting substance HCFC-22 and its environmental implications in Botswana.**

We believe that this research will only be used for academic purposes and therefore under no circumstances shall the data gathered be revealed to any media or the public.

Thank you

Yours Faithfully

BA PHIL SUPPLIES (PTY) LTD
P.O. BOX 11544, TATITOWN
TEL: 73061438 / 71357070
TEL/FAX: 2403891

....

Ms Baboga Emang

Managing Director

burs

botswana unified revenue service

head office

private bag 0013, plot 53976, kudumatse road, gaborone, botswana
tel: (+267) 363 8000, fax: (+267) 363 9999

Ref: BURS/OCG PLA2 III

21st March, 2017

Bongayi Kudoma
UNISA
Pretoria
South Africa

Dear Madam,

RE: REQUEST TO CONDUCT RESEARCH

Reference is made to your request brought on the 21st March, 2017, to conduct a study on a topic reading "**An Evaluation of the management systems of an ozone depleting substance HCFC-22 and its environmental implications in Botswana**".

We are pleased to inform you that your request has been granted, on the conditions that the information obtained from this organisation shall not, in any way, be used for any other purposes other than the intended use (i.e. educational purposes), as indicated in your proposal.

Your cooperation, in this regard will be highly appreciated. We wish you all the best in carrying out your research.

Thank you.

Yours Faithfully,

O. Okgethile
For/COMMISSIONER GENERAL

APPENDIX F: ETHICS APPROVAL LETTERS

UNISA university of south africa

CAES RESEARCH ETHICS REVIEW COMMITTEE

National Health Research Ethics Council Registration no: REC-170616-051

Date: 01/02/2017

Ref #: **2017/CAES/011**
Name of applicant: **Ms B Kudoma**
Student #: **50519204**

Dear Ms Kudoma,

Decision: Ethics Approval

Proposal: Evaluation of the management systems of an Ozone depleting substance HCFC-22 and its environmental implications in Botswana

Supervisor: Prof M Tekere

Qualification: Postgraduate degree

Thank you for the application for research ethics clearance by the CAES Research Ethics Review Committee for the above mentioned research. Approval is granted for the project, *subject to submission of the relevant permission letters.*

Please note that the approval is valid for a one year period only. After one year the researcher is required to submit a progress report, upon which the ethics clearance may be renewed for another year.

Due date for progress report: 31 January 2018

Please note points 4 to 7 below for further action.

The application was reviewed in compliance with the Unisa Policy on Research Ethics by the CAES Research Ethics Review Committee on 01 February 2017.

The proposed research may now commence with the proviso that:

1) The researcher/s will ensure that the research project adheres to the values and

University of South Africa

principles expressed in the UNISA Policy on Research Ethics.

2) Any adverse circumstance arising in the undertaking of the research project that is relevant to the ethicality of the study, as well as changes in the methodology, should be communicated in writing to the CAES Research Ethics Review Committee. An amended application could be requested if there are substantial changes from the existing proposal, especially if those changes affect any of the study-related risks for the research participants.
3) The researcher will ensure that the research project adheres to any applicable national legislation, professional codes of conduct, institutional guidelines and scientific standards relevant to the specific field of study.
4) The questionnaire is quite long and the researcher should allow for breaks for respondents to ensure they are comfortable throughout the process.
5) Feedback should be given to all participating groups. The researcher must inform the Committee how this will be done.
6) Permission must be obtained from each private company before their employees are approached to participate. These permission letters must be submitted as they are obtained.
7) As the questionnaires asks for the name of the participants, the researcher must ensure that this information is securely kept once obtained. Feedback must be provided to the Committee as to how the questionnaires will be secured.

Note:

The reference number [top right corner of this communiqué] should be clearly indicated on all forms of communication [e.g. Webmail, E-mail messages, letters] with the intended research participants, as well as with the CAES RERC.

Kind regards,

Signature
CAES RERC Chair: Prof EL Kempen

Signature
CAES Executive Dean: Prof MJ Linington

UNISA university of south africa

CAES RESEARCH ETHICS REVIEW COMMITTEE

National Health Research Ethics Council Registration no: REC-170616-051

Date: 20/11/2017

Ref #: **2017/CAES/011**
Name of applicant: **Ms B Kudoma**
Student #: **50519204**

Dear Ms Kudoma,

Decision: Ethics Approval Renewal after First Review for period 01/02/2018 to 31/01/2019

Proposal: Evaluation of the management systems of an Ozone depleting substance HCFC 22 and its environmental implications in Botswana

Supervisor: Prof M Tekere

Qualification: Postgraduate degree

Thank you for the submission of your progress report to the CAES Research Ethics Review Committee for the above mentioned research. Approval is granted for the continuation of the project.

Please note that the approval is valid for a one year period only. After one year the researcher is required to submit a progress report, upon which the ethics clearance may be renewed for another year.

Due date for progress report: 31 January 2019

Please note points 4 to 7 below for further action.

The application was reviewed in compliance with the Unisa Policy on Research Ethics by the CAES Research Ethics Review Committee on 01 February 2017.

The proposed research may now commence with the proviso that:

1) *The researcher/s will ensure that the research project adheres to the values and principles expressed in the UNISA Policy on Research Ethics.*
2) *Any adverse circumstance arising in the undertaking of the research project that is relevant to the ethicality of the study, as well as changes in the methodology, should be communicated in writing to the CAES Research Ethics Review Committee. An amended application could be requested if there are substantial changes from the existing proposal, especially if those changes affect any of the study-related risks for the research participants.*
3) *The researcher will ensure that the research project adheres to any applicable national legislation, professional codes of conduct, institutional guidelines and scientific standards relevant to the specific field of study.*
4) *The questionnaire is quite long and the researcher should allow for breaks for respondents to ensure they are comfortable throughout the process.*
5) *Feedback should be given to all participating groups. The researcher must inform the Committee how this will be done.*

NB

6) *Permission must be obtained from each private company before their employees are approached to participate. These permission letters must be submitted as they are obtained.*

NB

7) *As the questionnaires asks for the name of the participants, the researcher must ensure that this information is securely kept once obtained. Feedback must be provided to the Committee as to how the questionnaires will be secured.*

Note:

The reference number [top right corner of this communiqué] should be clearly indicated on all forms of communication [e.g. Webmail, E-mail messages, letters] with the intended research participants, as well as with the CAES RERC.

Kind regards,

Signature
CAES RERC Chair: Prof EL Kempen

Signature
CAES Executive Dean: Prof MJ Linington
8 Dec '17.

APPENDIX G: LETTER CONFIRMING EDITING

Alexa Barnby

Language Specialist

Editing, copywriting, indexing, formatting, translation

BA Hons Translation Studies; APEd (SATI) Accredited Professional Text Editor, SATI

Mobile: 071 872 1334

Tel: 012 361 6347

alexabarnby@gmail.com

24 January 2020

To whom it may concern

This is to certify that I, Alexa Kirsten Barnby, an English editor accredited by the South African Translators' Institute, have edited the doctoral thesis titled "**AN EVALUATION OF THE PHASE-OUT MANAGEMENT SYSTEMS OF AN OZONE DEPLETING SUBSTANCE HCFC-22 AND ITS ENVIRONMENTAL IMPLICATIONS IN BOTSWANA**" by Bongayi Kudoma.

The onus is on the author, however, to make the changes and address the comments made.