Ozone layer depletion and population growth: a review of linked pressures on human health and the environment

Demand for ozone-depleting products, ultraviolet exposure, policy response and future risks

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***Abstract*—The thinning of the stratospheric ozone layer and the rapid growth of the human population are usually studied separately, yet they are closely connected. A larger and wealthier population has meant more refrigeration, air conditioning, aerosol products and foam insulation, all of which once relied on chemicals that destroy ozone. A thinner ozone layer in turn lets more ultraviolet-B (UV-B) radiation reach the ground, which affects a growing number of people through skin cancer, eye disease and weakened immune responses. This review examines how population growth contributed to the build-up of ozone-depleting substances (ODSs), how the Montreal Protocol weakened that link, and what health, ecological and material consequences remain for a world of eight billion people. A narrative synthesis of international assessments by the World Meteorological Organization (WMO), the United Nations Environment Programme (UNEP) and the United Nations, together with peer-reviewed studies, was used, and a short case study of India is included. The evidence indicates that the global phase-out is one of the most effective environmental agreements ever made, but that ageing, population growth in hot regions and the climate effect of replacement chemicals keep the problem alive in a different form. This is a literature-based review and does not report new field experiments or a quantitative meta-analysis.**

***Keywords*—ozone depletion; population growth; UV-B radiation; Montreal Protocol; chlorofluorocarbons; skin cancer; sustainability**

I. INTRODUCTION

The ozone layer is a thin region of the stratosphere, roughly 15 to 35 km above the ground, that absorbs most of the harmful UV-B radiation (280–315 nm) coming from the sun. Without it, life on land would look very different. In 1974, Molina and Rowland proposed that chlorine released from man-made chlorofluorocarbons (CFCs) could destroy ozone [1], and a decade later scientists working in Antarctica reported a large seasonal loss of ozone over the continent [2]. These findings triggered one of the fastest international responses to an environmental threat on record.

During the same decades the human population grew at a rate with no historical precedent. There were about 2.5 billion people in 1950, around 5 billion in 1987 and 8 billion by November 2022 [3]. Each additional person brings demand for food, medicine and comfort, and for most of the twentieth century a good share of that demand was met with refrigerators, air conditioners, spray cans and foam products that contained ODSs.

Ozone depletion and population growth are therefore linked in both directions. Population and consumption helped create the problem, and the resulting increase in UV-B exposure affects more people, and more outdoor activity, than it would have in a smaller world. This review brings the two themes together and asks what can be learned for managing other environmental problems that grow with human numbers.

A. Aim and objectives

The aim is to synthesize evidence on the links between population growth and ozone depletion and to identify practical measures for reducing the remaining risks.

- Explain how ODSs damage the ozone layer and how population-linked demand increased their use.
- Summarize health, ecological and material effects of increased UV-B radiation.
- Examine the policy response, including the Montreal Protocol and its amendments.
- Recommend measures for governments, industry and individuals.

II. REVIEW METHODOLOGY

A narrative literature-review approach was used. Priority was given to the WMO and UNEP scientific assessments of ozone depletion [4], [7], the United Nations population estimates [3], and peer-reviewed papers on atmospheric chemistry, health effects and policy [1], [2], [5]–[6], [8]–[12]. These sources were chosen for their broad geographic scope, transparent authorship and relevance to the five themes of the review: chemistry, population-linked demand, health, ecosystems and materials, and governance.

This paper is not a preregistered systematic review or a meta-analysis, and it reports no new experiments, interviews or measurements. Statistics from different reports may use different years and accounting conventions, so they are interpreted in context rather than combined as if directly comparable. Population values in the figures and tables are rounded.

III. LITERATURE REVIEW

A. Discovery and chemistry of ozone loss

Ozone (O_3) is formed and destroyed continuously in the stratosphere. CFCs are very stable near the ground, so they drift slowly upward and are broken apart by strong ultraviolet light at high altitude, releasing chlorine atoms. A single chlorine atom can take part in thousands of

reactions that convert ozone into ordinary oxygen [1], [5]. Losses are greatest over the poles, where very cold winter air forms ice clouds on whose surfaces chlorine becomes chemically active; when sunlight returns in spring, ozone is destroyed rapidly, producing the Antarctic ozone hole [2].

B. Population, consumption and ODS demand

The literature agrees that ODS emissions depended on three factors together: the number of people, the consumption per person, and the technology used to deliver a service such as cooling. Industrialized countries accounted for most early consumption, and developing countries became the main growth area later, which shaped the design of the treaty [4], [13].

C. Montreal Protocol and recovery

The latest WMO assessment reports that the controlled ODSs have been phased out by about 99% and that the ozone layer is on track to return to 1980 levels around 2040 for most of the world, about 2045 over the Arctic and about 2066 over Antarctica [4]. Velders *et al.* estimated that the treaty has also avoided a large amount of warming because CFCs are powerful greenhouse gases [6].

D. UV-B and human health

Reviews of health effects identify skin cancer, cataract and suppression of some immune responses as the main harmful outcomes, and the production of vitamin D as a beneficial one [7], [8], [10], [11].

E. Ecosystems, agriculture and materials

Effects on plants, plankton and fish are generally smaller than those of climate change, habitat loss and overfishing, although UV-B can shape species interactions and nutrient cycles [7], [11]. Plastics, rubber and wood used outdoors degrade faster under stronger UV-B and warmer temperatures [11].

IV. POPULATION GROWTH AND DEMAND FOR ODS PRODUCTS

A. Refrigeration and cooling

The link between people and ODSs is clearest in refrigeration. As incomes rose after the Second World War, households bought refrigerators and later air conditioners in large numbers, and cold chains for food and vaccines spread across the world. CFC-12 and similar compounds were the working fluids in most of this equipment. Production climbed steeply from the 1960s and peaked in the 1980s, just as the population passed four and then five billion (Fig. 1, Table I).

B. Aerosols, foams and solvents

Spray cans, plastic foams for insulation and packaging, and cleaning solvents for electronics added further demand. Halons used in fire protection and methyl bromide used as a soil fumigant brought bromine into the stratosphere as well. These uses grew with urbanization, building construction and global trade.

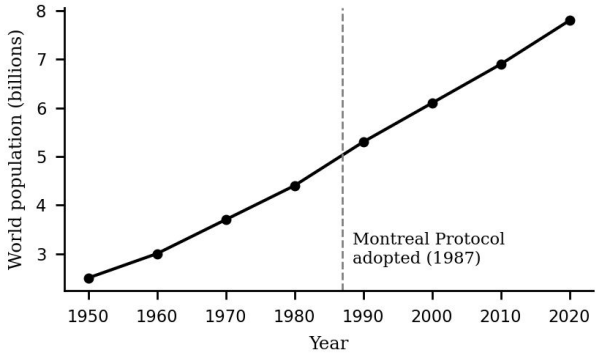

Fig. 1. World population, 1950–2020, from United Nations estimates [3] (rounded values). The dashed line marks the adoption of the Montreal Protocol.

TABLE I. POPULATION AND OZONE MILESTONES

Year	Population (billion)	Ozone-related event
1950	2.5	Rapid growth in CFC use begins
1974	~3.9	CFC–ozone theory published [1]
1985	~4.8	Antarctic ozone loss reported [2]
1987	5.0	Montreal Protocol adopted
2016	~7.4	Kigali Amendment agreed
2022	8.0	Ozone recovery under way [4]

C. Number of people versus pattern of use

Population size alone does not explain emissions. A small number of high-consuming households can cause more emissions than a larger number using little refrigeration, and a change in technology can cut emissions per person to almost nothing. This is why the Protocol focused on products and substances rather than on population itself.

V. EFFECTS ON HUMAN HEALTH

A. Skin cancer

Sunburn is the most common short-term outcome of overexposure, but the long-term concern is skin cancer. Basal cell and squamous cell carcinomas are the most frequent and are rarely fatal when treated early. Malignant melanoma is less common but causes most skin-cancer deaths and is associated with sunburn and intense, intermittent exposure in early life [8]. Population growth affects the numbers in two ways. A larger population contains more people who can fall ill, and populations are ageing, while skin cancer is a disease of accumulated exposure. Even if UV-B levels stay flat, the absolute number of cases may therefore keep rising for some years.

B. Eyes and immune system

Chronic UV exposure is a recognized risk factor for cortical cataract and for pterygium, a growth across the surface of the eye. A modelling study for the United States estimated that ozone decreases of 5% to 20% would raise cortical cataract cases by about 1.3% to 6.9% by 2050 [9]. UV-B can also suppress some immune responses in the skin, although evidence for effects on vaccination is limited [7], [8].

C. Vitamin D and balanced exposure

Not every effect of UV-B is harmful. Sunlight on the skin is the main natural source of vitamin D, which is needed for strong bones. Only short and modest exposure is required, so public advice has to balance enough sun against the risk of too much [10], [11]. Diet and supplements are safer options for people with little sun exposure.

D. Health responses

- Promote protective clothing, hats, sunglasses, shade and sunscreen, especially for children.
- Provide early detection and treatment of skin cancer and affordable cataract surgery.
- Give clear advice on vitamin D from diet and supplements for people at risk of deficiency.
- Use the UV Index in weather reports so that people can plan outdoor time.

VI. Effects on Ecosystems, Food and Materials

A. Terrestrial plants and crops

Plants respond to UV-B by producing protective pigments and thicker leaves, which can slightly reduce growth. For most crops the direct effect of present-day UV-B appears small compared with drought, heat and pests [11]. Even so, small changes matter when more than eight billion people depend on a limited area of farmland.

B. Aquatic systems and fisheries

Phytoplankton form the base of ocean food webs and take up large amounts of carbon dioxide. UV-B can damage them near the surface, and it can harm the eggs and larvae of fish living in clear water. Overfishing, warming and pollution are generally judged to be larger threats to fish stocks, with UV-B adding to them rather than leading [7], [11].

C. Materials and the built environment

Plastics, rubber, paints and wood are slowly broken down by sunlight. As cities grow to house more people, more of these materials are used outdoors in pipes, window frames, cables and cladding. Stabilizers give good protection, but higher UV-B and warmer temperatures can shorten service life or raise the cost of making products last [11].

VII. Case Study: India

India is a useful example because of its size. With roughly 1.4 billion people it is now the most populous country in the world [3], and demand for refrigeration and air conditioning is rising quickly with incomes and summer temperatures. India joined the Montreal Protocol in the early 1990s, followed the longer phase-out schedule granted to developing countries, and ratified the Kigali Amendment in 2021 [13].

Two lessons stand out. First, a large and growing population can take part in a successful phase-out when financial and technical support is available. Second, the next challenge is mainly about energy rather than ozone: the choice of efficient, low-warming refrigerants will decide how much the growing demand for cooling adds to climate change.

VIII. Policy Response: The Montreal Protocol and Beyond

A. A treaty that worked while the population grew

The Montreal Protocol, adopted in 1987, set limits on production and consumption of ODSs and was revised several times to cover more chemicals and bring forward end dates. Population kept growing, yet ODS use fell sharply, which shows that rising numbers of people do not have to mean rising harm when technology and policy change [4], [6].

B. Replacement chemicals

The HCFCs and HFCs that replaced CFCs are less damaging to ozone (HFCs do not harm it at all), but many are strong greenhouse gases. The Kigali Amendment of 2016 was agreed to phase down HFCs, and its full implementation is expected to avoid a few tenths of a degree of warming by 2100 [4].

C. Compliance and monitoring

In 2018 researchers reported an unexpected rise in global emissions of CFC-11, which pointed to new, unreported production [12]. The episode shows that long-term atmospheric monitoring and enforcement remain essential even for treaties considered successful.

IX. Comparative and Cross-Sector Analysis

Population growth, energy use, refrigeration, health care and climate all interact with the ozone problem. Fig. 2 summarizes the pathway from population-linked demand to ODS emissions, ozone loss and the resulting effects, and shows where the Montreal Protocol interrupted the chain.

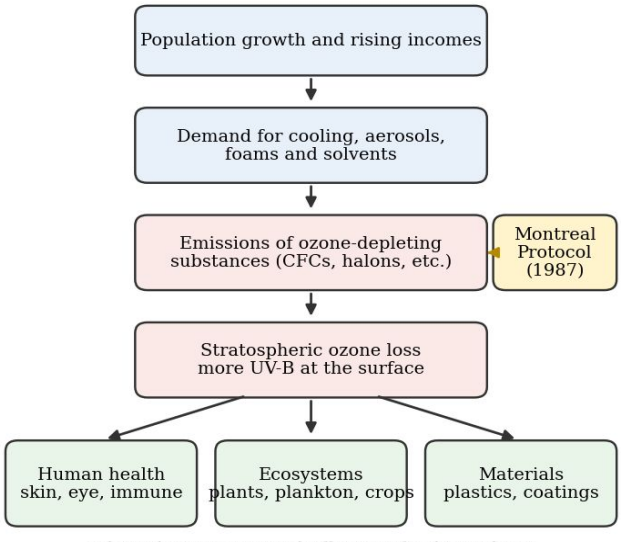

Fig. 2. Conceptual pathway from population growth and demand to ozone loss and its effects, and the point of policy intervention.

A. Interactions and trade-offs

Measures can shift rather than remove impacts. Efficient air conditioners reduce electricity demand but may use

refrigerants with high warming potential. Warmer weather may keep people outdoors for longer and raise UV exposure, while greenhouse gases that warm the lower atmosphere cool the stratosphere and can slow ozone recovery in some regions [4], [7]. Life-cycle assessment is therefore needed to identify real net benefits.

B. Equity

The burdens are unevenly distributed. Outdoor workers, children, older adults, people with fair skin and people in sunny low-income regions with limited health care face higher risks, while the benefits of cooling and refrigeration were enjoyed first by wealthier countries. Fair implementation requires technical and financial support, access to information and affordable protective measures.

C. Monitoring indicators

Useful indicators include the concentration of ODSs in the atmosphere, total column ozone, the UV Index at the surface, skin-cancer and cataract incidence, HFC consumption and the energy efficiency of cooling equipment. Every indicator should define its unit, baseline year, data source and uncertainty.

X. INTEGRATED RECOMMENDATIONS

A. Government and regulators

- Maintain atmospheric monitoring and enforce the controls on ODSs and HFCs.
- Support developing countries with funding, training and technology transfer.
- Include UV protection and skin-cancer screening in public-health programmes.

B. Industry and project developers

- Choose refrigerants with low ozone and low warming potential and design for leak-free equipment.
- Recover and safely destroy old refrigerants and foam at end of life.
- Disclose methods and avoid unsupported environmental claims.

C. Communities and individuals

- Use sun protection and eye protection, particularly for children and outdoor workers.
- Maintain appliances and have old refrigerators and air conditioners serviced and recycled properly.
- Support evidence-based environmental decisions in local planning.

XI. RESEARCH GAPS AND FUTURE DIRECTIONS

Research needs include better regional data on UV exposure and its health effects, especially in low-income tropical countries, and studies of how climate change will change outdoor behavior and exposure. Interactions between UV-B, temperature and other stressors on crops and aquatic ecosystems are still poorly understood. Further work should compare the full life-cycle impact of refrigerants and cooling technologies, including energy use. A future systematic review could use documented databases, search strings and screening counts to quantify effects using consistent functional units.

XII. LIMITATIONS

This paper synthesizes selected authoritative literature and is not an exhaustive review of all global publications. Its broad descriptions cannot represent every region, product or exposure pattern. Estimates differ by reporting year, method and system boundary, so figures from different sources should not be added or compared as though they were calculated identically. The paper reports no new experimental data. Before submission, each reference and citation should be verified against the original publication and the manuscript should be checked using the journal's required similarity-detection process.

XIII. CONCLUSION

Ozone depletion and population growth have been connected mainly through the demand for products that contained ODSs. The Montreal Protocol is a rare case in which the two trends were separated: consumption of ODSs fell sharply while the number of people kept growing, and the ozone layer is expected to recover during this century [4].

Nevertheless, several issues remain. Skin cancer and cataract cases are likely to keep rising for some years because of ageing, population size and the long delay between exposure and disease. Replacement chemicals must be managed so that they do not worsen climate change, and continued monitoring is needed to detect illegal production. Public awareness of sun protection is a cheap and effective measure. The story of the ozone layer is therefore less a finished chapter than a useful guide for dealing with other environmental problems that grow with the human population.

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