J Environ Stud Sci
DOI 10.1007/s13412-015-0224-1

# Introduction to the special issue on ozone layer protection and climate change: the extraordinary experience of building the Montreal Protocol, lessons learned, and hopes for future climate change efforts

**Penelope Canan · Stephen O. Andersen · Nancy Reichman · Brian Gareau**



**Abstract** This special issue on Ozone Layer Protection and Climate Change reflects the leadership of the Association of Environmental Studies and Sciences (AESS) in drawing interdisciplinary attention to important environmental issues. The authors are scientists, diplomats, regulatory authorities, environmental activists, and scholars who are intimately involved in actions that protect the stratospheric ozone layer and climate. This issue provides new information and insightful analytic summaries of critical issues in the protection of the atmospheric environment and is also an urgent appeal to professors and students to place atmospheric protection prominently in thinking, research, teaching, and professional activities related to "sustainable development." The authors describe and document the bold steps taken by individual and institutional leaders involved in the Montreal Protocol to thwart catastrophic ozone layer destruction, which incidentally, albeit on a sound scientific basis, addressed climate change. Because of strong leadership, effective networking, and concepts such the "precautionary principle" and "start and strengthen," the Montreal Protocol is considered to be the most successful global environmental treaty. For example, thanks to innovative approaches adopted by both industry and government, the Montreal Protocol has already replaced about 85 % of ozone-depleting greenhouse gases with low global warming potential alternatives and increased product energy efficiency. But hardwork is needed to overcome the important challenges that remain, such as the phasedown of the 15 % of alternatives that are high global warming potential hydrofluorocarbons. Scientists, government officials, scholars, and business people must push for higher standards to achieve the combined goals of reducing both ozone-depleting substances and greenhouse gases.

**Keywords** Montreal Protocol · Stratospheric ozone layer · Ozone hole · Climate change · Start and strengthen · HFCs · CFCs

## Introduction

This special issue on Ozone Layer Protection and Climate Change reflects the leadership of the Association of Environmental Studies and Sciences (AESS) in drawing interdisciplinary attention to addressing important environmental issues. The authors are scientists, diplomats, regulatory authorities, environmental activists, and scholars who are intimately involved in actions that protect the stratospheric ozone layer and climate. This special issue provides new information and insightful analytic summaries of critical issues in the protection of the atmospheric environment at a time when many scholars and citizens do not appreciate how far civil society has come and where it still needs to go in order to ensure our planetary future. The collection of essays is also an urgent appeal to professors and students to place atmospheric protection prominently in thinking, research, teaching, and professional activities in "sustainable development." In doing so, the special issue extends the plenary session that opened the 2014

A list of acronyms and suggestions for Montreal Protocol core readings can be found at Appendices I and II.

P. Canan · S. O. Andersen (✉) · N. Reichman · B. Gareau
Institute for Governance & Sustainable Development (IGSD), Washington, DC, USA
e-mail: soliverandersen@aol.com

Published online: 07 February 2015

annual meeting of the AESS titled: "Welcome to the Anthropocene: From Global Challenge to Planetary Stewardship," convened under the leadership of AESS President Wil Burns at the New York City campus of Pace University, June 11–13th.

The conceptual domain of *Sustainable Development* is now crowded, confused, and oftentimes hackneyed, with unintegrated emphases on its three pillars: social equity, economy, and environment, as well as on techno- and eco-centered fixes (Hopwood et al. 2005, p. 41) that range from radical reform to status quo approaches. There is room for all, encompassing wider views, and for interaction among disciplines to improve each in dialogue (Bell and Morse 2008). The political domain of sustainable development is critical to human survival but stalled, with the refreshing exception that the Montreal Protocol has been continuously strengthened and has been supported globally by every persuasion and perspective.

The authors of this special issue describe and document the bold steps taken by individual and institutional leaders involved in the Montreal Protocol to thwart catastrophic ozone layer destruction, which incidentally, albeit on a sound scientific basis (Gao, this issue), addressed climate change. Thanks to innovative approaches adopted by both industry and government, the Montreal Protocol has already replaced about 85 % of ozone-depleting greenhouse gases (GHGs) with low global warming potential (GWP) alternatives and increased product energy efficiency and is now taking on the phasedown of the 15 % of alternatives that are high-GWP hydrofluorocarbons (HFCs). Many scholars and social critics also argue that because "Business as Usual" (BAU) has no credibility in any sustainable development framework, particularly climate change, but also in some aspects of the ozone layer issue, existing global institutions like the United Nations Environment Programme (UNEP) need to reinvent and reimagine themselves for desired global impacts. It is time both to ensure the successful completion of global efforts to protect the ozone layer and to use ozone regime institutions to control greenhouse gases.

Citizens, public policy makers, and private enterprise managers responded to scientific warnings that chlorofluorocarbons (CFCs) and other chlorinated and brominated synthetic chemicals were deleterious to the stratospheric ozone layer, which protects the Earth against the harmful effects of ultraviolet (UV) radiation. The story of the UNEP Montreal Protocol (1987, as amended and adjusted) is a riveting account of the leadership, imagination, and the unswerving dedication of thousands of experts (typically volunteers) and organizations who showed the world how to reverse damage to the ozone layer caused by decades of industrial activity and chemical emissions. Truly, this was a matter of planetary survival, but the scientific proof was not (at the time) conclusive, and, therefore, leadership was required to initiate the process.

The Montreal Protocol of 1987, and its predecessor the Vienna Convention (1985), embraced the "precautionary principle," that action was required to avert disastrous effects of increased skin cancer and cataracts, disruption of human immunity, damage to agricultural crops and natural ecosystems, and other effects before scientific uncertainties of cause and effect were resolved. Guided by the precautionary principle and a dedication to evidence-based actions, amazing individuals created new institutions for global governance where there had been none. The complexity of the subject matter meant that science was the foundation (see Gao, this issue; Zaelke and Borgford-Parnell, this issue), a restored ozone layer was the guiding vision, and the strategy would be "start small and progressively strengthen" and "learning by doing and sharing," with reliance on the world's best independent scientific, technical, and economic advice shared directly with the countries participating in the Protocol unedited and uncensored for political convenience.

The "start-and-strengthen approach" of the Montreal Protocol required credible, reliable, up-to-date advice on science, industry, and technology. Trusting that new developments in science and technology would bring new directions for strengthening the chemical controls, energy efficiency, and the climate regime, the Parties (i.e., participating nation-states) established three assessment panels—Scientific Assessment Panel (SAP), Environmental Effects Assessment Panel (EEAP), and the Technology and Economic Assessment Panel (TEAP)—for expert periodic review and direct advice to the parties. The TEAP, under the direction of Dr. Stephen O. Andersen and others (most recently Marta Pizano, Bella Maranion, and Ashley Woodcock), ascended as the knowledge bank for adjustments and amendments to the treaty. The TEAP organized itself into six Technical Options Committees (TOCs) for pertinent industrial sectors (aerosols, foams, refrigeration, solvents, halons, and methyl bromide) and one Economic Options Committee. Each TOC was led by developing and developed nation co-chairs. The experts on the TEAP formed policy, program, and project networks within the ozone regime (Canan and Reichman 2002), as they represented governments, industries, academic disciplines, and non-governmental advocacy groups. The landmark global collaboration between multilateral scientific and technological bodies, i.e., SAP, EEAP, TEAP[1] and the Intergovernmental Panel on Climate Change (IPCC), produced an outstanding special report, called *Safeguarding the ozone layer and the global climate system: Issues related to HFCs and PFCs (perfluorocarbons)*. The extraordinary cross fertilization made for swift, accurate, and reliable assessments for the parties and supported speedy diffusion of innovation.

Strong leadership is the hallmark of this success story. Dr. Mostafa Tolba, at the time Executive Director of the United Nations Environment Program (UNEP), is credited as the instrumental architect of the Montreal Protocol and for his

[1] A list of acronyms can be found at the end of this Introduction.

strong skills of persuasion, which initially brought 24 countries and the European Economic Community to negotiate, sign, and ratify the agreement that went into force on January 1, 1989 (Benedick 1998; Canan and Reichman 2002; Andersen and Sarma 2002; Parson 2003; Kaniaru 2007). The role played by the UNEP OzonAction Programme along with the United Nations Development Programme (UNDP), United Nations Industrial Development Organization (UNIDO), and World Bank in facilitating the extraordinary and unique engagement of National Ozone Units of 146 developing countries in unison with the industrialized countries to eliminate ozone depleting substances would be recalled in the history books for times to come, as illustrated by Shende, in this special issue. The regional networks of National Ozone Units catalyzed by UNEP OzonAction Programme and the passionate networks of policy and technology experts produced an amazing success story of regulation guided by collaboration across business, industry, government, non-governmental organizations (NGOs), and academia as skillfully as the world has ever seen.

Many think that the stratospheric ozone layer has been "fixed," that it is old news, or that it is just a matter of time before it will be "restored." But the truth is that the ozone layer remains endangered, and climate change could overwhelm ozone recovery and plunge Earth into a decline that would take centuries to reverse. On 10 September 2014, the UNEP Scientific Assessment Panel (SAP) summarized its latest Scientific Assessment (UNEP/World Meteorological Organization (WMO), 2014) as follows:

- •"The Earth's protective ozone layer is well on track to recovery in the next few decades…[and the] Protocol will have prevented 2 million cases of skin cancer annually by 2030…"
- •"The Montreal Protocol has now reduced these (ozone-depleting greenhouse gas) emissions by more than 90%…[which is] about five times larger than the annual emissions reduction target for the first commitment period (2008–2012) of the Kyoto Protocol…"
- •"What happens to the ozone layer in the second half of the 21st century will largely depend on concentrations of $CO_2$, methane, and nitrous oxide—the three main long-lived greenhouse gases in the atmosphere. Overall, $CO_2$ and methane tend to increase global ozone levels. By contrast, nitrous oxide, a by-product of food production, is both a powerful greenhouse gas and an ozone depleting gas…"

Here is the good news: by reducing ozone-depleting substances (ODSs), the Montreal Protocol reduced greenhouse gases (GHGs), and, in transforming technology, the Protocol improved energy efficiency and demonstrated that focused commitment can yield great success. In fact, most of the progress made to date on reducing greenhouse gases has been the result of successfully phasing out ozone-depleting substances via the Montreal Protocol (See Fig. 1). As Edmonds explains (2004, p. 421)

> Banning the production of chlorofluorocarbons (CFCs) had no direct effect on other pollutants. And yet CFCs have two natures. In their life as an atmospheric constituent, they act as a greenhouse gas. When they dissociate, they become an ozone-depleting substance. The motivation for banning the production of CFCs under the Montreal Protocol was primarily to protect stratospheric ozone. Yet, there was an ancillary climate benefit.

The underlying lesson is that environmental systems are so intertwined that solutions must never remain in isolation, as they might appear in an institutional silo. Solutions with staying power are those that recognize and act upon the ancillary consequences, whether they may be safety, climate, economic development, or cultural preference.

For instance, there is an opportunity to utilize the historical flexibility of the Montreal Protocol for an amendment that would phase down hydrofluorocarbons (HFCs)—used only as a replacement for ODSs and powerful GHGs—as they can now be replaced with energy-efficient alternatives that are safe for the ozone layer and have low or no global warming potential (GWP) (see Zaelke and Borgford-Parnell; Gao, this issue for elaboration).

We celebrate the Montreal Protocol for being "the most successful global environmental treaty" in history. In two pieces of this collection, the authors review the many forms that success can take and identify opportunities to build on these achievements (see Gonzalez, Taddonio, and Sherman; Downie, this issue). Yet, excellence is hard won and the ultimate success of the Montreal Protocol still faces important challenges (Downie, this issue).

Effective global environmental policy requires diligence to sustain it. As the original generation of institutional entrepreneurs who constructed and maintained the ozone layer protection regime peels off, a new generation of stewards must be recruited to embrace the high standards that made the Montreal Protocol such a success. This time, the sectors invited to the table for collaborative regulation would be more likely to come from innovations in end-user efficiency, conservation, power generation, alternative sources of energy, agriculture, and forestry (Pacala and Socolow 2004). Moreover, the GHG political game will be regional and urban compared to the ozone game, which was international in choosing new technology to supply the goods and services that previously depended on ODSs. This means that climate solutions that are insensitive to local growth concerns are unlikely to get the support garnered under the Montreal Protocol (See, by way of

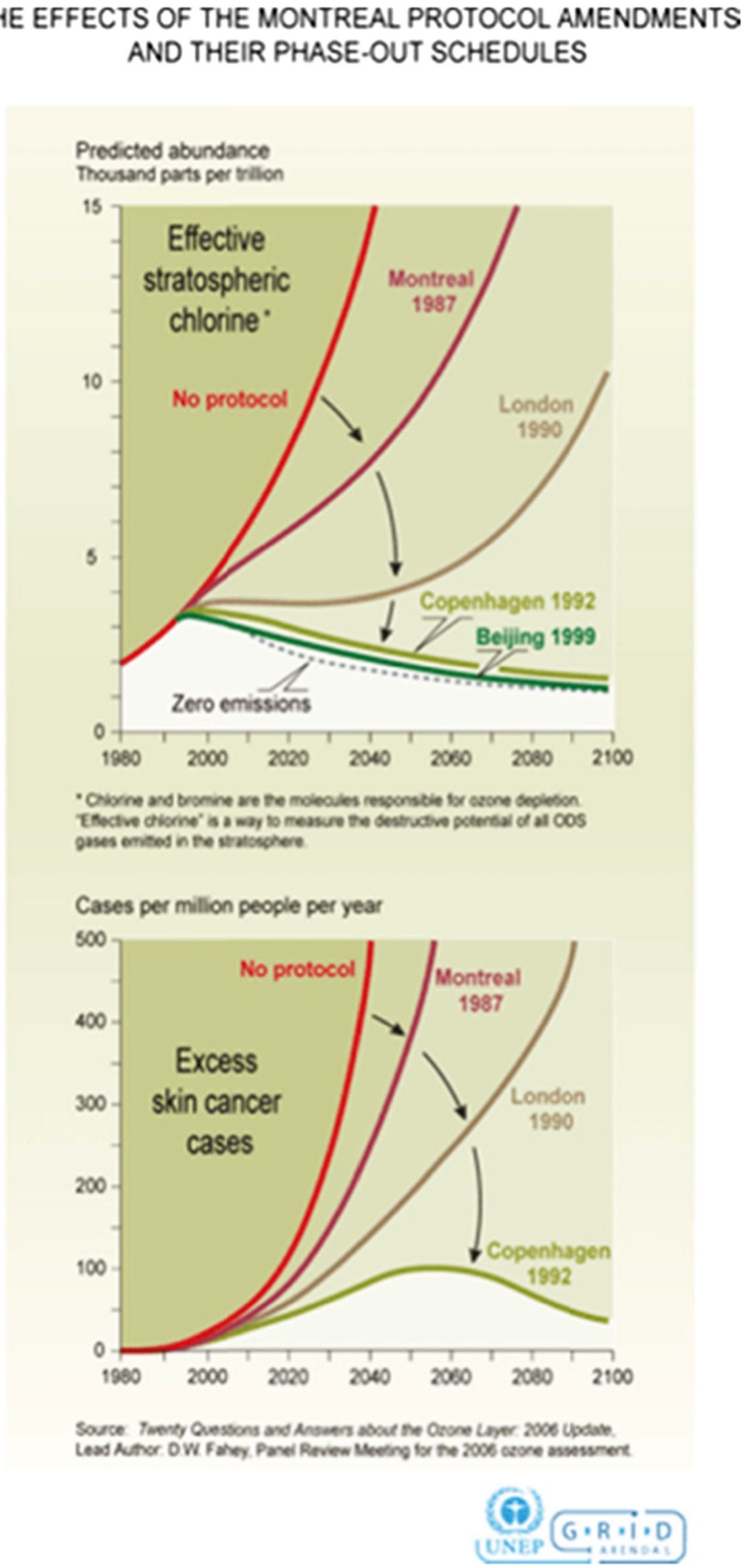


**Fig 1** The effects of the Montreal Protocol amendments on stratospheric chlorine and excess skin cancer cases

comparison Roberts and Parks 2006). So industries involved in local development and NGOs are more likely to play a more significant role once the silo walls between stratospheric ozone protection and global warming prevention crumble.

University administrators, teachers, and students must push for higher standards that boost the combined results of reducing both ODSs and GHGs. The bottom line is that the world is hiring university graduates who know what needs to be done and how to do it.

## Setting the stage for getting the most from this special issue

Although science has recognized planetary threats to the environment for more than a century, only in the past four decades have nations begun to take steps to address them (Axelrod and VanDeveer 2014, p.1). Today, there are thousands of multilateral environmental agreements (MEAs), including approximately a dozen major global environmental treaties (Peel 2014, pp. 61-62), with wide variance in development, effectiveness, and impact (Downie 2015, p. 83). Only one, the Montreal Protocol, enjoys universal praise as an example of successful human response to global anthropogenic problems.

With other "institutional entrepreneurs," Dr. Andersen in 1988 and thereafter conducted a global talent search to identify top-notch scientists and engineers, as well as leaders in business, non-governmental organizations, regulatory agencies, and academia to invite their voluntary participation on the TEAP (Canan and Reichman 1993; O'Neill 2015). Their first assembly and workshops took place at the University of California-Irvine in 1990 and was sponsored by the National Academy of Engineering. The meeting report was aptly entitled *Cross-Border Technology Transfer to Eliminate Ozone Depleting Substances*. Crossing borders referred to more than national boundaries; the hallmark of the Montreal Protocol is that its achievements are the result of the collaboration of partners from all sectors of the economy, including industry and non-governmental organizations, all of which deserve high praise for their active participation, leadership, and volunteerism (Cook 1996; Downie 2015).

## Systems compared to silos: challenges of complexity

Certainly, the international community has many reasons to be proud of the groundbreaking Montreal Protocol. The papers in this issue that delineate key elements of the treaty's "success" (Gonzalez, Taddonio, and Sherman; Downie) will astonish most readers; the accomplishments are simply amazing. Yet in spirit, design, and operation, the Montreal Protocol has always been treated as an experiment in progress, open to adjustments that comport with new science, new technology, and changes in national capacity and new political realities. Over time, the parties have amended the treaty to expand the list of chemicals that would be banned as science identified new "offenders" and adjusted treaty schedules to speed the phaseout of production and consumption. Astounding technological innovations permitted the parties to adjust their expectations regarding the speed at which yesterday's "miracles" could be replaced worldwide, and in all cases counter success to such replacement has been confined to a minority of cases (e.g., the methyl bromide phaseout), and even those cases eventually have been set to rights (See Gareau 2013 and Gareau, this issue for elaboration). Today, appreciation of the systemic feedbacks among GHGs and the synthetic compounds targeted in the Montreal Protocol require that scholars and policy makers consider institutional adjustments.

As this special issue goes to press, diplomats and policy experts gather to consider a proposal by the Federated States of Micronesia and another by Canada, Mexico, and the USA, to amend the Montreal Protocol to control HFCs, which are being used predominantly as replacements for CFC and hydrochlorofluorocarbons (HCFCs) being phased out under the Montreal Protocol. According to the Environmental Protection Agency (2014a, b), "Global benefits (of an HFC Amendment) can yield significant reductions of over 90 gigatonnes of carbon dioxide equivalent ($CO_2$ eq.) through 2050." Zaelke and Borgford-Parnell's contribution to this special issue unpacks the amazing opportunity awaiting us in this amendment for combatting global climate change.

## Contributions to this special issue

The inspiration for this special issue was the AESS plenary session at the 2014 annual meeting entitled "The Extraordinary Experience of Building a Global Regulatory Regime That Works: How the Montreal Protocol Saved the Ozone Layer and Is Helping to Save the Climate" and the organized discussion that followed, entitled "The Montreal Protocol at a Crossroads: What Needs Urgent Attention Now and How That Is Connected to Climate Change." The plenary was introduced by comic, writer, and actor Jennifer Joy's monologue about the ozone layer from Tony Kushner's award-winning play, "Angels in America: Millennium Approaches" (1993).[2] In the AESS plenary presentations and subsequent discussions, panelists exchanged ideas with conference scholars about improving the treaty and considered specific measures to address the connection between ozone layer depletion and climate change. To create this special issue for JESS, we have included papers based on the presentations by the distinguished individuals on the plenary panel, enrolled several AESS members who were active in the follow-on discussion session and invited "ozone regime

[2] http://jenniferjoyonline.com.

experts" to contribute to the continuing conversation. The collection covers an extensive territory, provides historical insights, presents criteria for excellence, and includes caution signs for the future. Be sure to "Google" the names of the authors listed here to learn more about some of the exciting, diverse career choices facing students interested in global environmental stewardship.

## The eight papers in this special collection

*Metrics of Montreal Protocol Success* by Marco Gonzalez, Kristen N. Taddonio, and Nancy J. Sherman sets the stage and will amaze readers with the compelling story of how all nations found consensus in the necessity of protecting Earth against stratospheric ozone depletion. *Managing Short-Lived Climate Forcers in Curbing Climate Change: An Atmospheric Chemistry Synopsis* by Song Gao builds the case for phasing down HFC short-lived climate pollutants under the Montreal Protocol. *Networks to Save the World* by Rajendra Shende tells how developing countries were empowered to work together for access to technology, financial support, joint action, fairness, and equity. *Lessons from Stratospheric Ozone Protection for Climate* by Stephen O. Andersen provokes readers by humanizing the government and industry leadership, elaborating the strategy of cooperation, debunking popular myths about the motivation and motives of the Montreal Protocol, and suggesting that climate topics as difficult as coal reduction can be resolved if lessons from the Montreal Protocol are applied. *Lessons from the Montreal Protocol Delay in Phasing Out Methyl Bromide* by Brian J. Gareau describes how the agricultural industry and other actors, backed by powerful national governments (Australia, Canada, USA), threatened the scientific basis, integrity and momentum of the Montreal Protocol. *The Importance of Finding the Path Forward To Climate-Safe Refrigeration and Air Conditioning: Thinking Outside the Box and Without Limits* by Stephen O. Andersen and Nancy Sherman shows how technical brainstorming and free thinking can raise the bar on carbon efficiency. *The Importance of Phasing-Down Hydrofluorocarbons and other Short-lived Climate Pollutants* by Durwood Zaelke and Nathan Borgford-Parnell elaborates on why and how the Montreal Protocol can phase down HFCs in collaboration with climate treaties just in time to avoid going over the 2°C climate guardrail. *Still No Time for Complacency: Evaluating the Ongoing Success and Continued Challenge of Global Ozone Policy* by Downie concludes the special issue with a look back and forward on climate protection and reiterates the call-to-action by professors and students to carry on the campaign for a world safe for future generations.

## Contributing experts (in alphabetical order)

Dr. Stephen O. Andersen is currently the Director of Research at the Institute for Governance & Sustainable Development (IGSD). For 25 years, he co-chaired the Montreal Protocol's Technology and Economic Assessment Panel. Among his many publications are Andersen and Sarma's *Protecting the Ozone Layer: the Official United Nations History* (2002) and its sequel with Sarma and Taddonio's *Technology Transfer for the Ozone Layer Lessons for Climate Change* (2007). Dr. Andersen is the architect of the TEAP: he designed it, recruited many of its expert members, managed their collaboration, inspired their extraordinary work, and carefully documented its "start-and-strengthen" steps to the successful phaseout of ozone-depleting chemicals. He has earned awards from the governments of Brazil, Iraq, Japan, Thailand, the Russian Federation, the USA, and Vietnam, as well as industry awards from Japan and the USA; and the prestigious Career Achievement Medal from Service to America.

Nathan "BP" Borgford-Parnell is a law fellow at IGSD focusing on short-lived climate pollutants (SLCPs) and carbon negative solutions and a climate science, policy, and law advisor to Centro de Estudios para el Desarrollo Sostenible (Bogota, Colombia). Nathan is also the founder of Valkyrie Energy, a renewable energy development and consulting firm for the expansion of sustainable low-carbon energy around the globe. Nathan was a Peace Corps volunteer in Albania from 2003–2005. He holds a J.D. and M.A. from American University and a B.A. from the University of Washington.

Dr. Penelope Canan is an emeritus professor of Sociology at the University of Southern Florida and previously professor at the University of Denver and University of Hawaii. Dr. Canan was also an Executive Director of the Global Carbon Project, one of the Earth System Science Partnership of the International Geosphere-Biosphere Program (IGBP), the International Human Dimensions Programme on Global Environmental Change (IHDP), the World Climate Research Program (WCRP), and Diversitas. Dr. Canan earned the *Women Making History Award*, the United States Environmental Protection Agency (USEPA) *Best of the Best Stratospheric Protection Award* and the *Driscoll Master Teacher Award* at the University of Denver (1988). She was a founding member and lead author of the Montreal Protocol Economic Options Committee and her book with Dr. Nancy Reichman, *Ozone Connections: Expert Networks in Global Environmental Governance*, was published in English by Greenleaf (2002) and in Japanese by Nippon Hyoronsha (2005).

David Downie is an associate professor of Politics and Environmental Studies at Fairfield University and co-author, with Pam Chasek, of the popular book, *Global Environmental Politics* (6th ed, 2014). He joined Fairfield University in 2008 to head its Environmental Studies Program, having spent 14 years at Columbia University in research, teaching, and

administrative positions at the Earth Institute and School of International and Public Affairs. He has attended dozens of global environmental negotiations, including on ozone, and written extensively on the ozone layer regime and other issues.

Song Gao is an atmospheric chemist by training and is currently an associate professor in the Division of Math, Science and Technology at Nova Southeastern University (NSU) in Florida. His postdoctoral work at Caltech was among the first to identify a new mechanism for atmospheric aerosol formation and growth using a combination of novel analytical instruments. He has published numerous peer-reviewed papers on atmospheric and aerosol chemistry. At NSU, he supervises students on research regarding the chemical characterization of aerosols and their impact on climate change, regional ecosystems, and air pollution. Since 2010, he has been directing the Climate-Sustainability Lecture Series at NSU. He has served on ad hoc and standing review panels at National Science Foundation.

Dr. Brian J. Gareau, Assistant Professor of Sociology and International Studies at Boston College and author of the highly acclaimed book entitled *From Precaution to Profit: Contemporary Challenges to Environmental Protection in the Montreal Protocol* (Yale University Press, 2013), presents the "deviant case" among the TEAP technical option committees. One lesson learned from the Montreal Protocol experience has been the amazing *voluntary* involvement of industry in eliminating ODSs. Theoretically, it was always possible that an industrial sector could provide "the deviant case" and drag its heels. That is the topic addressed by his valuable case study of the Technical Options Committee and other actors for the pesticide/fumigant industry involved in the methyl bromide phaseout. Brian was a Peace Corps volunteer in Honduras from 1997–1999.

Marco Gonzalez was an executive secretary of the Montreal Protocol from 2002–2013 after more than 20 years of work in energy and environmental issues. He held senior positions in the Government of Costa Rica, including energy and telecommunication institutes, high technology centers, and the Ministry of Environment and the National Congress, where he spearheaded the legislative ratification of the Ozone Treaties. He actively participated in the implementation of treaties at national and international levels, chaired meetings of the Vienna Convention and the Montreal Protocol, and served as Vice Chairman and Chairman of the Executive Committee of the Multilateral Fund of the Montreal Protocol.

Dr. Nancy Reichman is a regulatory scholar in the Department of Sociology and Criminology at the University of Denver, editor of the journal *Law and Policy*, and co-author of *Ozone Connections: Expert Networks in Global Environmental Governance* (2003). Nancy is a professor of Sociology at the University of Denver.

Rajendra Shende chairs the TERRE Policy Center, a non-profit organization and think tank engaged in evidence-based policy development and demonstration-based project implementation on energy security and food security in the developing countries in general and in his native India in particular. Prior to this responsibility, Shende served for some 25 years as the Head of the OzonAction Branch of the UNEP Division of Technology, Industry and Economics in Paris. Shende was trained as a chemical engineer and worked in the chemical manufacturing industry before he was tapped to serve on India's official negotiating team that pushed for the financial mechanism, the Multilateral Fund (established by the London Amendment of 1990) for developing country participation in the ODS phaseout.

Dr. Nancy J. Sherman is the Director of Technical Assessment at the Institute for Governance and Sustainable Development (IGSD). She is a recent Ph.D. graduate from the University of Virginia in Environmental Sciences. Her dissertation research utilized an interdisciplinary approach to examine the impact of climate change on the biologically diverse habitat of the Amur (Siberian) tiger in Far Eastern Russia. In a previous role as Vice President of Public Affairs for the Foodservice and Packaging Institute, Dr. Sherman participated in US EPA-led negotiations with industry representatives and four major environmental groups, which resulted in the voluntary phaseout of fully halogenated CFCs from polystyrene foam food and foodservice packaging. The phaseout became a model for voluntary CFC elimination by other industries globally.

Kristen N. Taddonio is an environment and energy technology specialist who has spent her career advancing programs that help businesses and individuals save money while reducing air pollution. She has published numerous papers, journal articles, and book chapters and has spoken at conferences around the globe on alternatives to ozone depleting substances and greenhouse gases in a variety of technical applications. Taddonio is a co-author with Stephen O. Andersen and K. Madhava Sarma of the book *Technology Transfer for the Ozone Layer: Lessons for Climate Change* (Earthscan: 2007) and was a co-chair of the Montreal Protocol Technology and Economic Assessment Panel (TEAP) Task Force on the continuing TEAP legacy. Taddonio holds a Masters degree in International Science and Technology Policy from George Washington University and currently works for the United States Department of Energy's Building Technologies Office.

Durwood Zaelke is the founder and president of the Institute for Governance and Sustainable Development (IGSD), director of the Secretariat of the International Network for Environmental Compliance and Enforcement (INECE), and co-founder of the Bren School of Environmental Management at the University of California at Santa Barbara.

## Appendix I

List of acronyms and abbreviations

| | |
|---|---|
| A/C | Air conditioner |
| AC&R | Air conditioning and refrigeration |
| AEES | Association of Environmental Studies and Sciences |
| AFCEE | Air Force Center for Environmental Excellence |
| AFEAS | Alternative Fluorocarbon Environmental Acceptability Study |
| AFRL | Air Force Research Laboratory, Wright Patterson |
| BAU | Business-as-usual |
| CCUS | Carbon capture, use, and storage |
| CFC | Chlorofluorocarbon |
| CIAP | Climatic Impact Assessment Program (USA) |
| $CO_2$ | Carbon dioxide |
| $CO_2^-$ | eq. Carbon dioxide equivalent |
| CMA | Chemical Manufacturers Association (USA) |
| CUE | Critical use exemption (Montreal Protocol) |
| DEC | Digital Equipment Corporation |
| DENIX | DoD Defense Environmental Network and Information eXchange (USA) |
| DTIE | Division of Technology, Industry and Economics (UNEP OzonAction) |
| EC | European Commission |
| EEAP | Environmental Effects Assessment Panel (Montreal Protocol) |
| EMBU | Emergency methyl bromide use |
| ENGO | Environmental non-governmental organization |
| EOP | Economic Options Panel (Montreal Protocol) |
| EOR | Enhanced oil recovery |
| EPA | Environmental Protection Agency (USA) |
| EU | European Union |
| EUE | Essential use exemption (Montreal Protocol) |
| FCCC | Framework Convention on Climate Change |
| FPI | Foodservice and Packaging Institute |
| GHG | Greenhouse gas |
| Gt | Gigatonne (one billion tonnes) |
| GWP | Global warming potential |
| HARC | Halons Alternative Research Corporation |
| HBFC | Hydrobromofluorocarbons |
| HCFC | Hydrochlorofluorocarbon |
| HFC | Hydrofluorocarbon |
| HFO | Hydrofluoroolefin |
| HUNC | Halon Users National Consortium |
| ICOLP | Industry Cooperative for Ozone Layer Protection |
| IEP | Institute for Economics and Peace |
| IGSD | Institute for Governance & Sustainable Development |
| INGO | Industry non-governmental organization |
| IPCC | Intergovernmental Panel on Climate Change |
| JICOP | Japan Industrial Conference for Ozone Layer Protection |
| LAN | local area network |
| LCCP | Life cycle climate performance |
| MACCPP | Mobile Air Conditioning Climate Protection Partnership |
| MAC | Mobile air conditioner (conditioning) |
| MAN | Metropolitan area network |
| MEA | Multilateral environmental agreement |
| MLF | Multilateral Fund (Montreal Protocol) |
| MOP | Meeting of the Parties (Montreal Protocol) |
| NAS | National Academy of Sciences (USA) |
| NASA | National Aeronautics and Space Administration (USA) |
| NATO | North Atlantic Treaty Organization |
| NAWC | Naval Air Warfare Center, China Lake (USA) |
| NBP | Normal boiling point |
| NGO | Non-governmental organization |
| NHTSA | National Highway Traffic Safety Administration (USA) |
| NIK | Not in kind |
| NOU | National Ozone Unit |
| $N_2O$ | Nitrous oxide |
| ODP | Ozone-depletion potential |
| ODS | Ozone-depleting substance |
| ODGHG | Ozone-depleting greenhouse gas |
| OECD | Organisation for Economic Cooperation and Development |
| OEWG | Open Ended Working Group (Montreal Protocol) |
| OSHA | Occupational Safety and Health Administration (USA) |
| PAFT | Program on Alternative Fluorocarbon Toxicity Testing |
| PFC | Perfluorocarbons |
| RNC | Regional Network Coordinator |
| SAP | Scientific Assessment Panel (Montreal Protocol) |
| SEIC | Navy Shipboard Environmental Information Clearinghouse |
| SLCP | Short-lived climate pollutant |
| SNAP | Significant New Alternatives Policy Program (US EPA) |
| SST | Supersonic Transport |
| TAP | Technology Assessment Panel (Montreal Protocol) |
| TEAP | Technology and Economic Assessment Panel (Montreal Protocol) |
| TEWI | Total equivalent warming impact |
| TOC | Technical Options Committee (of the TEAP) |
| UN | United Nations |
| UNDP | United Nations Development Programme |
| UNIDO | United Nations Industrial Development Organization |

| | |
|---|---|
| UNEP | United Nations Environment Programme |
| US | United States |
| USDOT | United States Department of Transportation |
| USA | United States of America |
| USAF | United States Air Force |
| UV | Ultraviolet |
| WAN | Wide area network |
| WB | World Bank |
| WMO | World Meteorological Organization |

## Appendix II

Montreal Protocol core readings


Andersen SO, Halberstadt ML, Borgford-Parnell N (2013) Stratospheric Ozone, Global Warming, and the Principle of Unintended Consequences—An Ongoing Science and Policy Success Story. Journal of the Air & Waste Management Association (AWMA), Critical Review, published online 22 May. 10.1080/10962247.2013.791349 EISSN: 2162-2906 ISSN: 1096-2247

Andersen SO, Sarma KM (2002) Protecting the Ozone Layer: the United Nations History Earthscan Press, London (Official publication of the United Nations Environment Programme)

Andersen SO, Sarma KM, Taddonio KN (2007) Technology Transfer for the Ozone Layer: Lessons For Climate Change. Earthscan Press, London (Official publication of the Global Environment Facility (GEF) and the United Nations Environment Programme)

Andersen SO, Zaelke D (2003) Industry Genius: Inventions and People Protecting the Climate and Fragile Ozone Layer. Greenleaf Press, London

Andersen SO, Frech, Clayton and Morehouse, E Thomas (1997) Champions of the World: Stratospheric Ozone Protection Awards, US EPA, Washington, DC

Benedick R (1991) Ozone Diplomacy: New Directions in Safeguarding the Planet, Harvard University Press, Cambridge, MA; and the updated edition, Benedick, Richard (1998) Ozone Diplomacy: New Directions in Safeguarding the Planet, Enlarged Edition, Harvard University Press, Cambridge, MA

Brack D (1996) International Trade and the Montreal Protocol, Royal Institute of International Affairs/Earthscan, London

Brodeur P (1986) 'Annals of Chemistry: In the Face of Doubt', New Yorker, 9 June

Cagin S, Dray P (1993) Between Earth and Sky: How CFCs Changed Our World and Endangered the Ozone Layer, Pantheon, New York

Canan P, Reichman N (1993) Ozone Partnerships, the Construction of Regulatory Communities, and the Future of Global Regulatory Power, Law and Policy, Vol. 15, No. 1 (January): 61-74

Canan P, Reichman N (2002) Ozone Connections: Expert Networks in Global Environmental Governance, Greenleaf Publishing, Sheffield

Cogan DG (1988) Stones in a Glass House: CFCs and Ozone Depletion, Investor Responsibility Research Center, Washington, DC

Cook E (1996) Ozone Protection in the United States: Elements of Success, World Resources Institute, Washington, DC

Dotto L, Schiff H (1978) The Ozone War, Doubleday & Co, Barden City, NY

Downie D (2015) International environmental regimes and the success of the global ozone policy. In: Axelrod R, VanDeveer S (eds) The Global Environment, 4th edn. CQ Press, Washington, pp. 83-10

Downie D (2014) Stratospheric ozone depletion. In Harris P (ed) Routledge Handbook of Global Environmental Politics. Routledge, New York, pp. 373-387

Downie D (2012) The Vienna Convention, Montreal Protocol and global policy to protect stratospheric ozone. In: Wexler P, van der Kolk J, Mohapatra A, Agarwal R (eds) Chemicals, Environment, Health: A Global Management Perspective. Taylor & Francis, Oxford, pp. 243-258

Downie D (1993) Comparative Public Policy of Ozone Layer Protection. Political Science (NZ) 45:186-197

Farman, J, Gardiner B and Shanklin J (1985) Large Losses of Total Ozone in Antarctica Reveal Seasonal ClOx/NOx Interaction, Nature 315: 207-10

Gareau BJ (2010) A Critical Review of the Successful CFC Phase-Out versus the Delayed Methyl Bromide Phase-Out in the Montreal Protocol. International Environmental Agreements: Politics, Law, and Economics 10,3: 209-231

Gareau BJ (2012) The Limited Influence of Global Civil Society in the Montreal Protocol. Environmental Politics 21(1): 88-107

Gareau BJ (2013) From Precaution to Profit: Contemporary Challenges to Environmental Protection in the Montreal Protocol. "Yale Agrarian Studies" Series, Scott JC (Series Editor) Yale University Press, New Haven

Greene, O (1998) The System for Implementation Review in the Ozone Regime. In Victor DG, Raustiala K, Skolnikoff EB (eds) The Implementation and Effectiveness of International Environmental Commitments: Theory and Practice (Laxenburg: International Institute for Applied Systems Analysis) MIT Press, Cambridge, 89-136

Gribbin J (1988) The Hole in the Sky: Man's Threat to the Ozone Layer, Bantam, New York

Haas P (1992) Banning Chlorofluorocarbons: Epistemic Community Efforts to Protect Stratospheric Ozone, International Organization 46(1):187-224

Le Prestre PG, Reid JD, Morehouse ET (1998) Protecting the Ozone Layer: Lessons, Models and Prospects, Kluwer Academic Publishers, Boston

Litfin, KT (1992) Ozone Discourses: Science and Politics in Global Environmental Cooperation. Columbia University Press, New York

Metz B, Kuijpers L, Soloman S, Andersen SO, Davidson O, Pons J, Jager D, Kestin T, Manning M, Meyer L (2005) Intergovernmental Panel on Climate Change (IPPC)/Montreal Protocol Technology and Economic Assessment Panel (TEAP) Special Report on Safeguarding the Ozone Layer and the Global Climate System: Issues Related to Hydrofluorocarbons and Perfluorocarbons, Cambridge University Press

Miller A, Mintzer I (1986) The Sky Is the Limit: Strategies for Protecting the Ozone Layer, World Resources Institute, Washington, DC

Molina M, Rowland FS (1974) 'Stratospheric Sink for Chloro-fluoromethanes: Chlorine Atom-Catalyzed Destruction of Ozone', Nature, vol 249, 28 June

Molina M, Zaelke D, Sarma KM, Andersen SO, Ramanathan V, Kaniaru D (2009) Reducing abrupt climate change risk using the Montreal Protocol and other regulatory actions to complement cuts in CO2 emissions. *Proceedings of the National Academy of Sciences of the United States of America, 106*(49), 20616-20621. doi: 10.1073/pnas.0902568106

Newman PA, Oman LD, Douglass AR, Fleming EL, Frith SM, Hurwitz MM, Kawa SR, Jackman CH, Krotkov NA, Nash ER, Nielsen JE, Pawson S, Stolarski RS, Velders GJM (2009) What would have happened to the ozone layer if chlorofluorocarbons (CFCs) had not been regulated? Atmospheric Chemistry and Physics 9(6):2113-2128. doi: 10.5194/acp-9-2113-2009

Parson, EA (2003) Protecting the Ozone Layer: Science and Strategy. Oxford University Press, New York

Prather MP, Midgley P, Rowland FS, Stolarski R (1996) The Ozone Layer: The Road Not Taken, Nature 381: 551-554

Singh AK, Kumar M, Bagai A (2009) Ozone Protection and National Security - A military Perspective Toolkit for Defence Forces, OzonAction, United Nations Environment Programme, Paris, 1 November

Solomon S, Garcia RR, Rowland FS, Wuebbles DJ (1986) On the depletion of Antarctic ozone. *Nature, 321*(6072), 755-758

Tolba M, Rummel-Bulska I (1998) Global Environmental Diplomacy: Negotiating Environmental Agreements for the World, 1973–1992, MIT Press, Cambridge, MA

UNEP (2012) Handbook for the Montreal Protocol on Substances that Deplete the Ozone Layer (ninth Edition), UNEP, Nairobi: http://ozone.unep.org/Publications/MP_Handbook/MP-Handbook-2012.pdf

Velders GJM, Andersen SO, Daniel JS, Fahey DW, McFarland M (2007) The Importance of the Montreal Protocol in Protecting the Climate. PROCEEDINGS OF THE NATIONAL ACADEMY OF SCIENCES 104: 4814-4819

Velders GJM, Fahey DW, Daniel JS, McFarland M, Andersen SO (2009) "The Large Contribution of Projected HFC Emissions to Future Climate Forcing," in the PROCEEDINGS OF THE NATIONAL ACADEMY OF SCIENCES 106: 10949-10954

Velders GJM, Ravishankara AR, Miller MK, Molina MJ, Alcamo J, Daniel JS, Fahey DW, Montzka SA, Reimann S (2012) Preserving Montreal Protocol climate benefits by limiting HFCs. Science 335:922-923. doi: 10.1126/science.1216414, 2012

Velders GJM, Solomon S, Daniel JS (2014) Growth of climate change commitments from HFC banks and emissions. Atmospheric Chemistry and Physics 14: 4563-4572. doi:10.5194/acp-14-4563-2014

WMO (2014) Scientific assessment of ozone Depletion: 2014. World Meteorological Organization, Global Ozone Research and Monitoring Project—

Report No. 55. WMO, Geneva

WMO (2014) Assessment for decisions makers: scientific assessment of stratospheric ozone: 2014. World Meteorological Organization, Global Ozone Research and Monitoring Project—Report No. 56. WMO, Geneva

Zaelke D, Borgford-Parnell N (2014) Primer on Hydrofluorocarbons: Fast action under the Montreal Protocol can limit growth of HFCs, prevent 100 to 200 billion tonnes of CO2-equivalent emissions by 2050, and avoid up to 0.5 °C of warming by 2100, Institute for Governance & Sustainable Development, online at: www.igsd.org

## References

Andersen SO, Sarma KM (2002) Protecting the ozone layer: the United Nations history. Earthscan

Axelrod RS, VanDeveer SD (2014) The global environment: institutions, law, and policy, 4th edn. CQ Press/Sage Publications, Washington, DC

Bell S, Morse S (2008) Sustainability indicators. Measuring the immeasurable? 2nd edn, London: Earthscan. ISBN 978-1-84407-299-6

Benedick RE (1998) Ozone diplomacy: new directions in safeguarding the planet. Harvard, Cambridge

Canan P, Reichman N (1993) Ozone partnerships, the construction of regulatory communities, and the future of global regulatory power. Law Pol 15(1):61–74

Canan P, Reichman N (2002) Ozone connections: expert networks in global environmental governance. Greenleaf, Sheffield and (2005, Japanese translation). Nippon Hyoronsha, Japan

Cook E (1996) Ozone protection in the United States: elements of success. World Res Inst, Washington, DC

Downie DL (2015) International environmental regimes and the success of global zone policy. In: Axelrod, RS, VanDeveer SD (eds) The global environment: Institutions, law and policy, 4th edn Sage, Washington, DC, pp. 83-109

Edmonds J (2004) Unanticipated consequences: thinking about ancillary benefits and costs of greenhouse gas emissions mitigation. In: Field CB, Raupach MR (eds) The global carbon cycle: Integrating humans, climate, and the natural world. Island Press, Washington, DC, pp 419–430

Gareau BJ (2013) From precaution to profit: contemporary challenges to environmental protection in the Montreal protocol. Yale University Press, New Haven

Hopwood B, Mellor M, O'Brien G (2005) Sustainable development: mapping different approaches. Sustain Dev 13:38–52

Kaniaru D (ed) (2007) The Montreal Protocol: Celebrating 20 years of environmental progress, ozone layer and climate protection. Cameron May and United Nations Environment Programme, Cameron May Ltd, London

O'Neill K (2015) Architects, agitators, and entrepreneurs: International and nongovernmental organizations in global environmental politics. In: Axelrod, RS, VanDeveer SD (eds) The global environment: Institutions, law and policy, 4th edn Sage, Washington, DC pp.26-52

Pacala S, Socolow R (2004) Stabilization wedges: solving the climate problem for the next 50 years with current technologies, Science 305, 968-972. See also: http://www.azimuthproject.org/azimuth/show/Stabilization+wedges

Parson EA (2003) Protecting the ozone layer: science and strategy. Oxford University Press, New York

Peel J (2014) International law and the protection of the global environment. In: Axelrod RS, VanDeveer SD (eds) The global environment: Institutions, law and policy, 4th edn CQ Press/Sage Publications, Washington, DC, pp 53-109

Roberts JT, Parks BC (2006) A climate of injustice: global inequality, north-south politics, and climate policy. MIT Press, Cambridge

US Environmental Protection Agency (2014a) Ozone layer protection: amendments to the Montreal Protocol. http://www.epa.gov/ozone/intpol/history.html. Accessed 26 June 2014

US Environmental Protection Agency (2014b) Recent international developments under the Montreal Protocol: 2014 North American amendment proposal to address HFCs under the Montreal Protocol. http://www.epa.gov/ozone/intpol/mpagreement.html. Accessed 28 June 2014