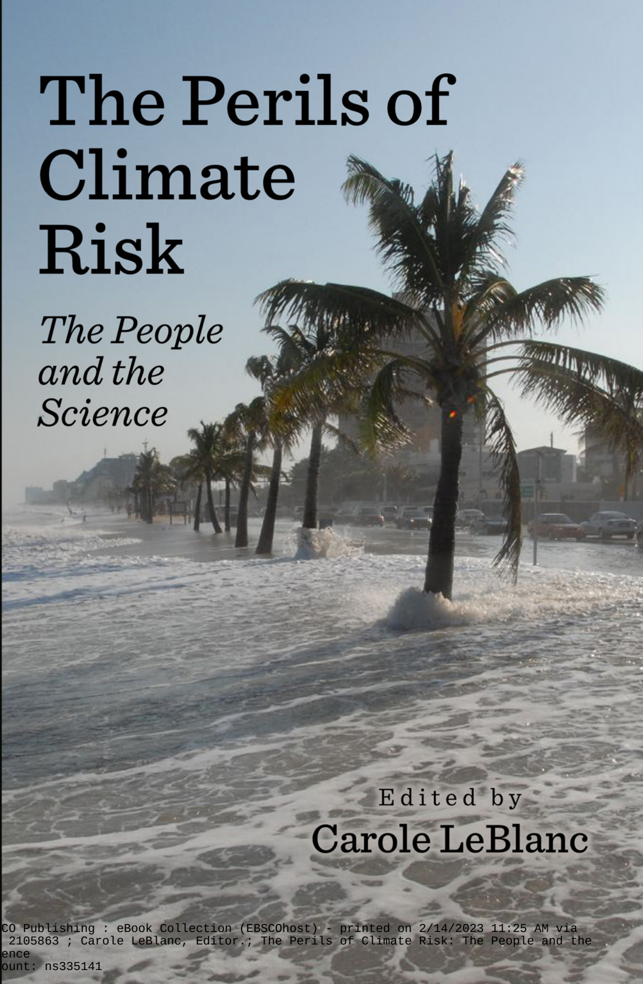

The Perils of Climate Risk

The People and the Science

Edited by

Carole LeBlanc

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IN MEMORIAM

I am told that my father, Clarence Andrew Fraughton, was not quite 18 years old when he enlisted in the United States (U.S.) Navy following the Japanese invasion of Pearl Harbor that ushered the U.S. into World War II. He served as a submariner, quipping years later that,

"The line t● get int● the Air F●rce was just t●● l●ng."

Such are the young decisions that shape the rest of our lives. He was a 'radar man' back in the day when the exposure effects of things like radiation were hardly known. And so it was that when he returned home (submarine service was then the most dangerous duty in the military, with casualty rates around 20 percent), he was anxious to start a family.

That is the beginning of my story, as I am the oldest of three daughters. While I am sure he wanted a son, I benefited from his advice long before the current women's movement: that in our country, I could accomplish anything, be anyone, if only I was willing to work hard. In chapter three, *Putting Women in Power* of **Demystifying Climate Risk Volume I: Environmental, Health, and Societal Impacts** (LeBlanc, C. ed., Cambridge Scholars Publishing, 2017), Maggie Roth wrote:

> "…women are under-represented at all levels of the STEM[1] career pipeline, from interest and intent of majoring in a STEM field in college to having a career in a STEM field, such as clean energy…"

I would be less than truthful if I said that being the first or only woman in certain professional settings wasn't daunting, or even frightening, at times. But his counsel never left me. Amazing, the power of a father's influence on a little girl.

Thanks, Dad.

[1] STEM, or Science, Technology, Engineering, and Mathematics is the term that groups these academic disciplines together. The term is particularly useful in addressing related educational policies and curriculum choices to improve competitiveness, having implications for workforce development and other issues of national and international importance. The acronym arose after an interagency meeting at the U.S. National Science Foundation (NSF) chaired by NSF Director Rita Colwell. One of the first NSF projects to use the acronym was STEMTEC, the Science, Technology, Engineering and Math Teacher Education Collaborative at the University of Massachusetts Amherst in 1998.

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PREFACE

This book constitutes the findings of the second in a series of three workshops on climate risk. The workshops were held in Maine, a New England state in the northeast section of the United States (U.S.) known for its environmental beauty bordering Canada.

As a recently retired chemist and policy advisor to U.S. and state governments, the original intent of the first workshop was to ensure that the knowledge and wisdom gained by my contemporaries was shared with the next generation of students and professionals. Some of that work concerned implementing the Montreal Protocol, the international treaty that successfully restored earth's ozone layer over a quarter of a century, and still protects our planet's atmosphere to this very day. It seemed reasonable that the 'lessons learned' from that experience would be helpful to today's younger scientists and public policy wonks, now focused on another atmospheric threat: climate change.

Only weeks after the first workshop, the 2016 U.S. presidential election was held. Now it would no longer be just a matter of sharing technical expertise. Now the focus would necessarily shift from mentoring, to protecting scientific integrity, and sometimes even to protecting scientists themselves:

Silencing Science: An Insider's Take on the Trump Administration's Efforts to Undermine Federal Climate Policy was a March 15, 2018 event hosted by Maine Audubon. It featured Maine native, Joel Clement[1], former director of the U.S. Interior Department's Office of Policy Analysis. Clement's July 19, 2017 Washington Post opinion editorial reads, in part:

> "I am not a member of the deep state. I am not big government. I am a scientist, a policy expert, a civil servant and a worried citizen. Reluctantly, as of today, I am also a whistleblower on an administration that chooses silence over science…On June 15, I was one of about 50 senior department employees who received letters informing us of involuntary reassignments… I believe I was retaliated against for speaking out publicly about the dangers that climate change poses to Alaska Native communities. During the months preceding my reassignment, I raised the issue with White House officials,

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[1] Joel Clement is currently a senior fellow with the Center for Science and Democracy at the Union of Concerned Scientists (see Table 12.2).

> senior Interior officials and the international community, most recently at a UN <United Nations> conference in June. It is clear to me that the administration was so uncomfortable with this work, and my disclosures, that I was reassigned with the intent to coerce me into leaving the federal government…Let's be honest: The Trump administration didn't think my years of science and policy experience were better suited to accounts receivable…Trump and Zinke[2] might kick me out of my office, but they can't keep me from speaking out."

Truthfully, these are trying times. Speaking of truth:

> "I am the way and the truth and the life."
>
> King James Version, chapter 14, verse 6

Of all the nouns, in all the languages that Jesus could have chosen to describe himself, he chose these three. And 'truth' is right in the middle of them. Most historians agree that Jesus probably spoke Aramaic, the common language of Judea in the first century. While there may be different ancient words with different shades of meaning for the English word, 'truth', this humbles me and gives me pause. Might it also serve to strengthen all scientists in our current pursuit of 'truth'?

Shortly before his death on August 25, 2018, a U.S. senator penned these farewell words to the American people:

> "Do not despair of our present difficulties but believe always in the promise and greatness of America, because *nothing is inevitable here* <emphasis added>. Americans never quit. We never surrender. We never hide from history. We make history."[3]
>
> John McCain

A prisoner of war in North Vietnam for 5½ years, McCain lived there longer than at any other address in the U.S. up to that time in his life. *Tortured to the point where he would never again be able to lift his arms up*

[2] A Trump nominee in late 2016, Interior Secretary Ryan Zinke moved to open coastal waters and public lands for oil and gas leasing, and recommended shrinking up to four national monuments. He resigned December 15, 2018 amid allegations of unrelated misconduct.

[3] For Senator McCain's entire statement, see: https://www.cnn.com/2018/08/27/politics/john-mccain-farewell-statement/index.html.

over his head, he would still insist in his final public statement that he considered himself to be the luckiest person on earth.

Certainly, whatever problems we face today we can conquer, provided we face them together.

Carole LeBlanc
Wells, Maine, USA

ACKNOWLEDGEMENTS

The editor thanks all participants to the 2nd Annual International Technical Workshop on Climate Risk, whether remote or in person. A special thanks to Sam Higuchi of the United States (U.S.) National Aeronautics and Space Administration (NASA) for his leadership in the workshop's content. Recognition is owed to Sam's co-workers from Leidos, in particular, Erik Tucker and Kim Gotwals, for their assistance in running the workshop.

The editor also thanks Cambridge Scholars Publishing for their support. Following the workshop in October 2017, a number of climate change developments occurred in 2018. These included some very important scientific reports with political and policy ramifications that necessitated postponing the publishing deadline to cover the issues sufficiently. Almost immediately thereafter, the U.S. government was partially shut-down, requiring another delay. I am most grateful for the publisher's patience.

Neighbors Megan Walsh and Ed Rogowski, both of whom are teachers, provided personal and moral support, as did my friend and cousin, Robert Stelin. Contributing author Phil Barnes shared ideas about the book's title. Colleagues and students at the University of New England in Biddeford, Maine, U.S. were likewise instrumental in making this book possible. Without them, it would have been unfeasible to focus on the possibility of a promising future, in light of the current dire climate data reported herein.

INTRODUCTION

Demystifying Climate Risk: Volumes I and II (LeBlanc, C. ed., Cambridge Scholars Publishing, 2017), published following the 2016 Annual International Technical Workshop on Climate Risk, focused on environmental, health, and societal implications; and industry and infrastructure implications, respectively. Both books conclude with the statement:

> "It is our <the workshop participants'> intention to continue the theme of systems thinking as an essential approach to addressing the multitude of challenges posed by climate change."

In, *Tools for Systems Thinkers: The 6 Fundamental Concepts of Systems Thinking* (2017)[1], Dr. Leyla Acaroglu[2] identifies the following essential elements to systems thinking:

1. Interconnectedness;
2. Synthesis;
3. Emergence;
4. Feedback loops;
5. Causality; and
6. Systems mapping.

The publication of this book, **The Perils of Climate Risk: The People and the Science**, follows the 2017 Annual International Technical Workshop on Climate Risk and a plethora of climate change developments in 2018. These developments included some very important scientific reports with political and policy ramifications that are examined here.

Based on participants' expertise, the book begins by covering related scientific topics, such as the assessment of climate change science itself, and tracking global changes in greenhouse gas (GHG) concentrations. Technical tools are described, including: (1) engineering designs to control water after

[1] https://medium.com/disruptive-design/tools-for-systems-thinkers-the-6-fundamental-concepts-of-systems-thinking-379cdac3dc6a.
[2] Dr. Acaroglu was named the 2016 Champion of the Earth by the United Nations Environment Programme (UNEP).

intense rainfall; (2) a pollution prevention (P2) options analysis system; and (3) the manufacture of pharmaceuticals involving catalysis to reduce the use of toxins.

The next section focuses on the human side of climate change. For example, climate change impacts on public health, and the role of indigenous peoples in dealing with climate change impacts. Other chapters discuss the influence of maritime ports on climate change, and the economics of climate action.

Significantly, and in keeping with the 'systems approach', one author contributes to both the scientific (e.g., theoretical) and societal (e.g., applied) sections regarding climate risk management. The book's twelve contributors hail from government, business, and academia, including a Nobel Peace Prize recipient and Fulbright Scholars. In all chapters, the editor strove to maintain the authentic voice of each of the contributing authors. Acronyms are defined within each of the chapters, so that the reader does not have to consult a glossary or preceding parts of the book.

From December 22, 2018 to January 25, 2019, the United States (U.S.) government was partially shut down, the longest in history. Some of the book's contributing authors were either affected government employees (who should be paid their back salaries upon reinstatement) or government-contracted employees (who will most likely not be paid their missing salaries). Realizing that these colleagues may not even to able to read their emails, I still sent them a message which read in part:

> "In anticipation for the government's return to work, allow me to thank former co-workers for how much I value your efforts in helping to keep our environment safer, on behalf of humans and other creatures! Now, as a private citizen, it is even more clear to me how important your work is. Again, thank you so much. I hope that you were able to enjoy the Holiday Season as much as possible."

After the elections for the U.S. House of Representatives on November 6, 2018, the select committee on climate change, eliminated in 2010, was expected to be revived. The purpose of the committee would be to:

> "Prepare the way with evidence <for energy conservation and other climate change mitigation legislation>. It <the committee> was clearly still needed to educate the public about the impact of more frequent extreme weather events."
>
> Speaker of the House, Nancy Pelosi

Depending on your point of view, this is either an exciting or a terrifying time to be a climate scientist. If you are fortunate enough to have a healthy sense of humor, perchance it is both.

From my perspective, there are three classes, critical to human health and happiness, that will always require our political attention:

- Children, including education;
- Animals, both wild and domestic; and
- The natural environment.

As different as these categories appear to be, they have one thing in common: they cannot vote! Consequently, they require our constant vigilance, similar to the battle for civil rights.

The natural environment is obviously the focal point of this book. After years of environmental abuse and neglect, much legislative progress was made circa 1970; the U.S. Clean Air Act, the U.S. Clean Water Act: you name it; we protected it. Laws like these have made considerable and long-lasting improvements to both public health and the environment. The mistake that my generation made is that we thought we had won the battle. But legislation like the U.S. Toxic Substances Control Act (TSCA), while visionary at its origin, remains woefully outdated today.

Everything we needed to know, the extent and the consequences of unfettered climate change, was determined by the 1970s:

> "In 1974, the <U.S.> C.I.A. <Central Intelligence Agency> issued a classified report on the carbon-dioxide problem. It concluded that climate change had begun around 1960 and had 'already caused major economic problems throughout the world.' The future economic and political impacts would be 'almost beyond comprehension.' Yet emissions continued to rise, and at this rate, MacDonald[3] warned, they could see a snowless New England, the swamping of major coastal cities, as much as a 40 percent decline in national wheat production, the forced migration of about one-quarter of the world's population. Not within centuries within their own lifetimes."
>
> Nathaniel Rich[4]

[3] Gordon MacDonald, an American geophysicist (1929-2002).

[4] From, *Losing Earth: The Decade We Almost Stopped Climate Change*, which appeared as the only story in the August 2018 edition of the New York Times Magazine. https://www.nytimes.com/interactive/2018/08/01/magazine/climate-change-losing-earth.html. The reporting was supported by the Pulitzer Center: http://pulitzercenter.org/.

Still, new books on climate change abound, do they not? So why add another one to the list? Perhaps the author of chapter eight, *Traditional Knowledge and Climate Change Challenges: Anambra State, Nigeria Case Study*, says it best:

> "But despite over 40 years and about 900 environmental treaties in force, human-induced environmental change is pushing the earth system towards a critical tipping point which may be irreversible, unless urgent steps are taken to avert the disaster."
>
> Chizoba Chinweze

The solution remains the same as it was in the 1970s: sound, science-based public policy. The difference today, I fear, is that policies, even when legislated, are not enforced. The possible reasons for this are considered in the book's final chapter dealing with ethical and governance issues. Neither of these issues was addressed in the first two volumes leading up to this book.

Finally, it is hoped that the book's conclusion will bring the role of environmental stewardship into further clarity for the reader.

Carole LeBlanc
Wells, Maine, USA

Chapter Summaries

The science

Chapter One: *Assessing the Science of Climate Change*, by Dr. Don Wuebbles, provides an update to the understanding of climate change based on the latest authoritative assessment: Volume I of the 4th National Climate Assessment, also known as the Climate Science Special Report (CSSR). Focused on the U.S., the report reveals the climate knowledge gained since the publication of the third assessment in 2014. These findings, along with other research, include: (1) 2016 was the warmest year on record to date, with global temperatures expected to continue to rise; (2) heavy precipitation is increasing in intensity and frequency across the U.S.; (3) heat waves have become more frequent while cold waves have become less frequent in the country; (4) record-setting warm years are expected to continue in the U.S.; (5) earlier spring snowmelt and reduced snowpack are affecting water resources in the western states, increasing the possibility of serious drought before this century's end; (6) the increase in the number of large forest fires in the western states and Alaska since 1980 is expected to continue; (7) higher atmospheric water vapor concentrations, resulting from rising temperatures, will likely impact flooding events, particularly along the West Coast; (8) a hurricane's precipitation rate, intensity and/or frequency, depending on the storm's location in the Atlantic or Pacific Ocean, will increase; and (9) sea level rise (as much as 8 feet by the year 2100) will continue throughout the world – as the incidence of daily tidal flooding is accelerating in more than 25 Atlantic and Gulf Coast cities – and with higher-than-global-averages possible along the East and Gulf Coasts. It is extremely likely that human activity is the dominant cause of the observed warming for the period of 1951-2010, the contributions of natural forcing and internal variability being minor for the same time frame. The atmospheric carbon dioxide (CO_2) concentration is now over 400 parts per million (ppm), a level not seen for three million years, when the Earth was much warmer and sea levels higher. If carbon emissions continue to rise, human-caused changes to climate will result in even more, and perhaps irreversible, damage to, for example, human health, water, energy, transportation, agriculture, forests, and ecosystems. Dr. Wuebbles ends on a positive note, stating that we are more than capable as a species to reduce emissions by mitigation and to adapt to the changes already taking place.

Chapter Two: *Tracking Global Changes in Greenhouse Gas Concentrations*, by Dr. Steve Montzka, provides a thorough explanation of how and why the U.S. National Oceanic and Atmospheric Administration (NOAA) tracks greenhouse gas (GHG) concentrations. The paper communicates NOAA's findings in tracking changes in global atmospheric concentrations of long-lived GHGs (LLGHGs) and the underlying implications of these measured changes. While the main contributors to Earth's greenhouse effects are: (1) water vapor (50%); (2) clouds (25%); (3) carbon dioxide, CO_2 (20%); and (4) methane, nitrous oxide, halocarbons, ozone, etc. (5%), many human activities lead to the emission of LLGHGs (for example, the burning of fossil fuels emits CO_2). As a result, atmospheric concentrations of these gases are elevated substantially above natural levels. Consequently, NOAA overseas a global air sampling network. Based in Boulder, Colorado, U.S., NOAA's Global Monitoring Division (GMD) maintains a vast cooperative air sampling network of nearly 90 sites around the world, from the northern tip of Alaska to the Gobi Desert in Mongolia and even to the snowy desolate landscape of the Antarctic South Pole. Depending on the site, measurements are taken of the most abundant GHGs (CO_2, CH_4, and N_2O) and long-lived halocarbons[5] that are also potent GHGs. GMD's goal is to map LLGHG concentrations throughout the lower atmosphere of the entire world. Once a week, sampling flasks are filled and sent to the Boulder facility where they are analyzed on several instruments for the measurement of over 40 long-lived chemicals. The focus is on long-lived gases, i.e., gases having lifetimes of approximately one year or longer, as they are the largest contributors to climate warming today whose impacts will be felt for decades, even centuries, after being emitted. The ability of a trace gas (that is, atmospheric gases other than nitrogen, oxygen, and argon) to influence climate depends on its: (1) efficiency for absorbing available heat energy; (2) concentration; and (3) persistence. The effect of a trace gas on the energy balance of Earth's climate system can be expressed as a *radiative forcing* (warming influence), and serves as an index of the significance of the factor as a potential climate change mechanism. Analysis of measured global atmospheric concentrations reveals that CO_2 accounts for (1) two-thirds of the current atmospheric radiative forcing from all LLGHGs and (2) more than 80% of the increase in radiative forcing over the past 5 years from all LLGHGs. Furthermore, *the overall increase in radiative forcing from 2015 to 2016 was the second largest annual increase on record.* NOAA's Annual Greenhouse Gas Index (AGGI) is a measure of the climate-warming influence of long-lived trace gases and how that influence has changed since the Industrial Revolution. Its value in a given year reflects the warming influence (or radiative forcing) in that year relative to 1990, based on

[5] Halocarbons are chemicals in which one or more carbon atoms are linked with one or more halogen atoms: fluorine, chlorine, bromine or iodine.

atmospheric changes since 1750. *The value for the AGGI in 2017 of 1.41 means that the warming influence from human-derived emissions of LLGHGs has increased by 41% since 1990.* Radiative forcing provides an estimate of the warming influence supplied by a LLGHG at a point in time as a result of emissions in the past. It does not indicate how the warming influence from these gases will change in the future. The future of climate warming will reflect both the persistence of GHGs in the atmosphere today (their lifetimes) as well as the magnitude and persistence of current GHG emissions. As a result of the magnitude and changes noted in the recent past for LLGHGs emissions, total radiative forcing from these gases has steadily increased over time. Stabilizing climate will only be achieved by decreasing emissions of these gases to the point where radiative forcing stops increasing or even decreases. Given the dominant role of CO_2 in total radiative forcing and its recent increase, and in total GHG emission, any attempt to stabilize climate will need to focus on CO_2 emissions. Specifically, *CO_2 emissions need to decrease by 80% to stop the increase in its concentration and its associated radiative forcing*. But climate responds to overall radiative forcing, not just the forcing associated with one or two gases. These results indicate that anthropogenic (i.e., human-caused) warming by LLGHGs still continues to increase for several years after various emission reduction scenarios are phased in gradually. Since the 1990s and the passage of the Kyoto Protocol[6]: *(1) LLGHG emissions have instead increased by 24%; and (2) CO_2 emissions have increased by about 60%*. NOAA GMD's global atmospheric observations of LLGHGs are therefore invaluable to: (1) provide a measure of GHG emissions which enables identification of mitigation opportunities on global as well as local scales; and (2) enable an assessment of efforts to stabilize climate warming on global scales.

Chapter Three: *A "4th Wave" Perspective on Climate Risk Management*, by Sam Higuchi, documents the historical nature of the environmental movement by trends or "waves". The first three waves were characterized by conservation, regulation, and sustainable development, respectively. According to Richard MacLean, Director of Richard MacLean & Associates, LLC[7], the movement has now entered a fourth wave focusing on resources or, more precisely, "strategic resources positioning". Nationally, there is strong evidence for this with Executive Order (EO)

[6] An international treaty which extended the 1992 United Nations Framework Convention on Climate Change (UNFCCC) that committed state parties to reduce LLGHG emissions. The U.S. is a signatory to the treaty.

[7] https://rmacleanllc.com/.

13806, *Assessing and Strengthening the Manufacturing and Defense Industrial Base and Supply Chain Resiliency of the United States* and EO 13817, *A Federal Strategy to Ensure Secure and Reliable Supplies of Critical Minerals*, both signed in 2017. Internationally, the evidence is provided by the European Union (EU) publications: *Critical Raw Materials and the Circular Economy* and *Raw Materials Information System (RMIS).* The emphasis on resources can easily be translated to materials usage. This includes: (1) decarbonization – using less carbon-based fuels for energy in manufacturing products (mitigates climate change by reducing GHG emissions); (2) dematerialization – reducing the use of scarce materials/minerals in manufacturing products (conserves limited resources and decreases GHG emissions by eliminating the energy required to extract critical materials/minerals); and (3) detoxification – eliminating toxic material-chemicals in manufacturing products (reduces the release of toxic by-products, ozone depleting substances (ODSs), GHGs, etc., and resultant environmental contamination)[8]. Collectively, decarbonization, dematerialization and detoxification are elements of sustainable materials management (SMM). The scarcity of critical materials/minerals has been characterized as a "ticking time bomb" in the SMM paradigm. PricewaterhouseCoopers (PwC) defines scarcity-based manufacturing disruptions in three dimensions: (1) physical – due to natural disasters (hurricanes, et al.); (2) economic – due to price volatility, for example; and (3) geopolitical – due to export controls, conflict zones, etc. Moreover, materials are interconnected to water and energy, such that a direct impact on one will eventually impact the others, leading to potential supply chain disruptions. Consequently, businesses as well as nations must manage risks relative to SMM to maintain a competitive advantage. The author describes a number of climate risk frameworks originating from the concept of enterprise risk management (ERM). Three ERM components are important to manage climate-related risks: (1) event identification (e.g., extreme weather); (2) risk assessment; and (3) risk response. Linking these frameworks together creates a useful network to incorporate climate risk management into a financial-accounting approach. Two Australian publications are recommended: *Climate Change Adaptation in Industry and Business: A framework for best practice in financial risk assessment, governance and disclosure* and *Managing the Risks from Climate Change: An adaptation checklist for business.* Existing U.S. federal statutes can be

[8] For more information on the topic of Toxics Use Reduction (TUR), see chapter five, *Pollution Prevention Options Analysis System* by J. Marshall and chapter five, *Cleaning Solvents: How to Choose A Safer One* by J. Marshall in **Demystifying Climate Risk Volume II: Industrial and Infrastructure Implications** (LeBlanc, C. ed., Cambridge Scholars Publishing, 2017).

used to implement a similar financial-accounting framework, that is, statutes requiring a federal agency to: (1) safeguard its assets; (2) manage high-risk management challenges; (3) apply climate science research findings pursuant to its statutory duties under the federal agency's Authorization Act; and (4) apply climate science research findings pursuant to its statutory duties under a federal agency's duty to comply with federal laws. Linking these four statutory groups together likewise creates a networked financial-accounting framework for climate-related risk management. In summary, Mr. Higuchi presents several viable frameworks, including those with a solid financial basis, to help protect assets and supply chains from the risks associated with climate change for both business and government.

Chapter Four: *Adjusting Precipitation Intensity-Duration-Frequency (IDF) Curves in Engineering Design*, by Mark Klingenstein, examines why the adoption of climate-adjusted IDF curves may be appropriate for public agencies. In a previous paper, the author provided the following description of IDF curves:

> "An individual IDF curve presents rainfall intensity/duration combinations having a single specified return frequency. A series of <IDF> curves is therefore used to provide intensity/duration data for a range of specified return frequencies at a given location".[9]

Climate-adjusted IDF curves take into account the changes between IDF curves of the current climate and those of a projected future climate. In this paper, the author investigates the degree to which climate-adjusted IDF curves have been incorporated in the U.S. at the federal, state and municipal levels. He reports that:

- The Department of Transportation (DOT)'s Federal Highway Administration (FHWA) – recognizes the potential impact of climate change on transportation systems, including on the drainage systems serving those systems, and facilitates such climate-impact activities by considering them eligible for federal funding. While the FHWA does not mandate the use of climate change adjusted IDF data, FHWA indirectly encourages investigation of its applicability by

[9] *Climate Change Adjustment Of Intensity-Duration-Frequency Curves by M. Klingenstein*, **Demystifying Climate Risk Volume II: Industry and Infrastructure Implications** (LeBlanc, C. ed., Cambridge Scholars Publishing, 2017).

individual agencies with the development of the *U.S. DOT CMIP Climate Data Processing Tool.*

- State DOTs – a number of these agencies are investing energy and resources into the issue of climate change, and its impact on transportation infrastructure. However, none have determined that the use of climate adjusted IDF information is appropriate. Upon examination of states' DOT websites, California, Illinois, North Carolina, and Vermont address climate change in their hydraulic design manuals. Mr. Klingenstein provides a detailed explanation of each of these states' approaches.
- U.S. municipalities – while a significant number of large U.S. cities have ongoing/developing climate change action plans, only one city, New York City (NYC), was found to have developed or be developing climate change-adjusted IDF curves for the design of storm drainage systems. After much debate, the Mayor's Office of Recovery and Resiliency released a document in April 2017, the *Preliminary Climate Resiliency Design Guidelines, Version 1.0,* that provides design criteria adjustments to address increasing high temperatures, increased intense precipitation, and sea level rise. For increasing intense precipitation, the guidelines provide adjusted IDF curves for 5-year, 50-year and 100-year events, based upon the New York City Panel on Climate Change (NPCC) impact prediction modeling analyses. As climate science progresses, the guideline is expected to be further refined.

The study concludes that U.S. adoption of climate-adjusted IDF curves is limited, but that Canadian counterparts have apparently made more progress, perhaps because of the creation of an infrastructure vulnerability committee in that country. Welland, Ontario, Canada is a case in point: in order to ensure that new infrastructure would perform as designed for its entire service life, the city undertook an assessment utilizing data from the World Climate Research Programme. Published in 2012, it is unclear how much of the assessment's recommendations have been implemented at this time.

Chapter Five: *Pollution Prevention Options Analysis System,* by Dr. Jason Marshall, details the recent progress made in the field of alternatives assessment: "<the> process for comparing alternatives, usually to a chemical of concern, and identifying those that are safer".[10] In the mid-

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[10] https://www.turi.org/Our_Work/Research/Alternatives_Assessment/Alternatives_Assessment_Guidance.

1990s, the Massachusetts Toxics Use Reduction Institute (TURI) developed a tool to help companies systematically determine whether the TUR options under consideration may have unforeseen negative environmental, worker, or public health impacts. The tool is known as the Pollution Prevention Options Analysis System (P2OASys). By the 2000s, TURI's laboratory was using the P2OASys for projects involving solvent substitution in industrial cleaning operations, since organic solvents often have ozone depleting potentials (ODPs) and/or global warming potentials (GWPs). Research supported by the Society for Chemical Hazard Communication[11] compared the P2OASys to the Global Harmonized System (GHS) with the chief goal of replacing the subjective rankings of 'high', 'medium' and 'low' risks with actual endpoints wherever possible. This research revealed that the P2OASys often provided more restrictive (i.e., safer) values than the GHS standard. In instances where the GHS standard provided more stringent values, or additional hazard information, that information was incorporated into the P2OASys and new subcategories added to the assessment matrix as necessary. Key words from the GHS were also added to the P2OASys, as well as worst-case-scenario endpoints. P2OASys' cumbersome spreadsheet format was subsequently converted into a web-based interface with an integrative, drop-down menu, making data entry/selection easier. Dr. Marshall provides the reader with a P2OASys example for the alternatives assessment of the volatile organic compound (VOC), trichloroethylene (TCE). TURI continues to refine the P2OASys and to investigate other assessment tools to determine if including additional resources would make the P2OASys more universal. In closing, Dr. Marshall cautions users of the P2OASys that the tool generates a helpful, comparative score, and *not* a definitive value.

Chapter Six: ***Process Improvement in The Pharmaceutical Industry: Using Copper Catalysts***, by Ryan Conger, describes the application of green chemistry principles in the synthesis of pharmaceuticals by means of catalysis. Green chemistry can be defined as, "the design of chemical products and processes that reduce or eliminate the use and generation of hazardous substances".[12] Catalysis is the process of modifying a chemical reaction with small amounts of a reusable catalyst that can accelerate a reaction to completion, often for commercial purposes. Copper catalysts are useful in multicomponent reactions (MCRs) in which a product is assembled according to a cascade of reactions. In most cases, MCRs provide

11 https://www.schc.org/.

12 https://www.epa.gov/greenchemistry/basics-green-chemistry.

greener alternatives to multi-step syntheses because they are carried out in a single vessel and reduce waste. Compared to other catalysts such as the platinum group metals (PGMs), other advantages of copper include its: (1) abundance; (2) low toxicity; and (3) relative low cost. Copper catalysts may provide suitable alternatives to PGMs in medicinal chemistry. Moreover, copper-catalyzed azide-alkyne cycloaddition (CuAAC), known as "click chemistry", is considered one of the most powerful two-component coupling strategies in modern synthetic chemistry. CuAAC can often be performed at ambient, that is, safer room temperatures. The author concludes that the future of research in copper catalysts should include a comparison of old and new processes based on a life cycle assessment (LCA) approach. LCAs identify the material, energy, and waste associated with a given process. One such method was developed by the United Nation Intergovernmental Panel on Climate Change, IPCC GWP 100a, which analyzes GWPs expressed as kilogram (kg) CO_2 equivalents.

The people

Chapter Seven: *Death by Degrees*, by Dr. Syd Sewall, provides an overview of climate change as a public health issue following the publication of two seminal reports. In 2000, Physicians for Social Responsibility Maine Chapter (PSR Maine)[13] published the groundbreaking, **Death by Degrees: The Emerging Health Crisis of Climate Change in Maine**. In 2015, PSR Maine released the updated version – **Death by Degrees: The Health Crisis of Climate Change in Maine**. The public health perspective approaches disease rates as the outcome of a set of interacting risk factors impacting the overall population, the "determinants of disease", whereas clinical medicine deals with individual patients and their specific problems/risk factors. Climate change increases risks for a number of public health concerns, including: (1) respiratory health; (2) vector-borne diseases; (3) waterborne illnesses; (4) heat illness; and (5) mental health. The major impacts of climate change on each of these public concerns are: (1) contributing to asthma, respiratory diseases, cardiovascular events, and an extended allergy season in the accompaniment of air pollution; (2) an increase in the incidence of Lyme disease due to the range expansion of the disease-carrying tick, as well as the occurrence of the first human case of Eastern Equine Encephalitis in Maine in 2014; (3) potential surges of waterborne illnesses after flooding or excessive rainfall, such as algae contamination in Maine's shellfish industry due to sewage overflow; (4) a

[13] https://psrmaine.org/.

rise in cases of mild dehydration, heat exhaustion, and heat stroke (the total breakdown of the body's homeostatic mechanism) as a direct consequence of record-breaking temperatures and heat waves, especially dangerous for at-risk populations such as the elderly, and an increase in related hospitalizations; and (5) an upsurge in suicide rates and requests for mental health support after catastrophic storms (i.e., extreme weather events) and resultant long-term loss of homes, jobs, electric power, etc., with associated increases in emergency room (ER) visits, hospitalizations, and acute and chronic illnesses. Finally, as Board President of an organization primarily dedicated to the prevention of war, PSR Maine, Dr. Sewall discusses the sociological impact of conflicts potentially driven by the effects of climate change, such as natural resource degradation, ecosystem disturbances, food scarcities, and political upheaval.[14] The author identifies the global reduction of GHG production as the 21st century's biggest challenge.

Chapter Eight: *Traditional Knowledge and Climate Change Challenges: Anambra State, Nigeria Case Study*, by Chizoba Chinweze, examines soil erosion, the current major ecological challenge exacerbated by climate change in Anambra State, Nigeria in light of the indigenous people's ability to respond. Located in West Africa, Nigeria borders on the Atlantic Ocean's Gulf of Guinea, neighboring Cameroon, Chad, Niger, and Benin. Anambra is located in the southeastern part of Nigeria, with a landmass of 44,116 square kilometers (approx. 17,033 square miles). Anambra resides in the tropical zone, with an intermittent wet season and a 4- or 5-month dry season. The dry season along the West African coast experiences hazy, *harmattan* conditions, a dry, dusty easterly or northeasterly wind occurring from December to February. Average annual rainfall amounts to 1800 millimeters (approx. 71 inches), with bouts of intense precipitation. Relative humidity is continually high (65% or greater), with average temperatures ranging from 25°-32° Celsius (C) or 77°-90° Fahrenheit (F). The soil is deep red, porous, and unconsolidated. The main drainage system for the state is the Anambra River which empties into River Niger, along with a few tributaries such as the Omabala, Oyi, and Ezu Rivers. The topography consists mostly of pronounced rolling, long, steep slopes that enhance runoff velocities and result in the washing-off of topsoil, leading to soil erosion, the formation of gullies, and flooding on low-lying plains. The state contains a human population of about 4,182,032 (with a population density of about 900 persons per square kilometer or 0.4 square miles) in 127

[14] See also, chapter eight, *Traditional Knowledge and Climate Change Challenges: Anambra State, Nigeria Case Study*, by C. Chinweze for specific examples of potential climate-driven conflict.

communities with 27 different local governments. Founded on the 2014 United Nations Intergovernmental Panel on Climate Change (UN IPCC) concepts of risk classification and vulnerability assessment: (1) *40.1%* of Anambra is *severely* gullied – impacting *38.08%* of the population; (2) *27.8%* of Anambra is *moderately* gullied – impacting *28.33%* of the population; and (3) *32.1%* of Anambra is *mildly* gullied – impacting *30.47%* of the population. Farming (that is, subsistence agriculture), trading, and small-scale industries constitute the bulk of the state's economy. Residence of Sub-Saharan Africa (SSA) rely on local, natural resources for sustenance more than any other place on Earth. Accordingly, the people have come to understand and to value these resources over many years. Traditional ecological knowledge (TEK) is important in: (1) areas prone to gully formation, where native plant species and local soil management practices are used in attempts to manage and reduce the escalation of soil erosion and (2) in plain areas prone to flooding, where forest governance having cultural, religious, and spiritual significance is used in attempts to contain flooding. By 2050, other climate facts and risks in Africa include: (1) an increase in average temperatures of 1.5°C-3°C with additional increases expected to follow; and (2) 25%-40% of mammalian species in SSA national parks becoming endangered. By 2080, further expected changes include: (1) water stress, scarcity, and a potential increase in conflicts as almost all of the 50 river basins in Africa are transboundary; (2) compromised food crops solely dependent on rainfall for irrigation; and (3) increased vulnerability to a number of climate-sensitive diseases such as malaria. Consequently, the role of TEK is significantly limited by the region's (1) endemic poverty; (2) limited access to technology; and (3) poor public policy and institutional frameworks. The combination of: (1) high impact (over 96% of Anambra's population is impacted by gully formation caused by climate-related soil erosion) and (2) low adaptive capacity (the ability to prepare for, avoid, moderate, and recover from climate-related risks) makes Anambra State, Nigeria, highly vulnerable to climate change and variability. Substantial assets, i.e., funding, will be required to successfully address a burgeoning problem of this magnitude, including the use of advanced technologies.

Chapter Nine: *Maritime Ports: Impacts on Climate Change*, by Dr. Maurady, Farah Housni, and Dr. Phil Barnes, examines and compares the efforts of two major ports, (1) the Tangier Med Port in Morocco and (2) the Port of Aalborg, Denmark, to better understand and reduce their environmental impacts, including their energy usage and GHG emissions. The information obtained for this case study was obtained from interviews with knowledgeable port personnel. Besides their locations, the ports differ in terms of their size and age. Both ports represent economic development for the areas that they serve, and have sustainable development plans. Tangier Med Port's plan includes the use of ISO 14001:2015 EMS (environmental management system). Tangier has identified two objectives to reduce air pollution: (1) minimize the idling of trucks for loading and unloading; and (2) measure emissions from activities within the port area, a necessary component for ISO certification. The Port of Aalborg is one of the few CO_2-neutral ports in the world, and the first in Denmark. In 2014, the Port of Aalborg built a solar power plant to reduce GHG emissions, but the port does not currently seek GHG information from ships. Expanding Aalborg's networking capabilities with external stakeholders will provide opportunities to further decrease emissions. Each of the ports embarked on unique and specialized approaches to the problem of climate change. Yet this study demonstrates that, despite significant differences in culture between two ports separated by thousands of miles, the common challenges of reducing fossil fuel consumption and CO_2 emissions can lead to some common practices. Consequently, future progress will depend on better coordination of enhanced GHG data collection within the shipping, port operations, and transport supply chains.

Chapter Ten: *Climate Risk Management: Implementation Aspects*, by Sam Higuchi, identifies two key components for the successful implementation of climate risk management: first, a mutually acceptable climate database and second, mutually acceptable climate information sources. Further, the author suggests that providers of the science should consider shifting their focus from product outputs to customer service outcomes, if the objective is indeed to promote the initial use, and then the application, of currently available climate science. A number of resources are recommended: (1) a database for technical managers of large public works programs and projects – Downscaled CMIP3 and CMIP5 Climate and Hydrology Projections (U.S. Army Corps of Engineers, Bureau of Reclamation); and (2) the CMIP5 data in KNMI Climate Explorer at Climate Change Atlas, established by the United Nations Intergovernmental Panel on Climate Change (UN IPCC) as an authoritative, international climate database. These climate databases can serve as starting points towards actionable knowledge. Two credible sources of climate information are likewise recommended: (1) the U.S. Globe Change Research Program's National Climate Assessment, specific to the U.S. and (2) the IPCC's assessment reports for international applications. For the non-climate scientist, these two authoritative sources offer the greatest credibility and serve as the second step towards actionable knowledge. If further knowledge is required, the 2016 publication, *A Guidebook on Climate Science Scenarios: Using Climate Information to Guide Adaptation Research and Decisions*, by Ouranos is recommended. At some point, practitioners may need to move beyond just using sources of climate data and information, and conduct their own climate scenario analyses. According to the author, custom analysis requires an understand of three fundamental elements: (1) dimensional framework; (2) selection of scenarios; and (3) temporal aspects and each of these steps are detailed. The many advocates of this approach, including the Task Force on Climate-related Financial Disclosure (TCFD), envision custom climate scenario analyses as part of routine climate-related risk management for business. Finally, Mr. Higuchi provides additional resources for the reader in an appendix, including an Australian publication that offers a format based on a flowchart of data and references, and asks for answers to a series of five basic questions to assist the user with his/her project.

Chapter Eleven: *Is Serious Climate Action Sooner Than Later A Good Economic Bet?*, by Christopher Juniper, poses a very simple question with complex answers. In fact, the race to better manage GHGs in a timely manner was worthy of the 2018 Nobel Memorial Prize in Economic Sciences with the development of the Dynamic Integrated Climate-Economy (DICE) model by Yale University's Dr. William D. Nordhaus: GHG growth = gross domestic product (GDP) growth plus population growth +/- GHG intensity of the economy. This chapter explores both economic cost/benefit methodologies, and "non-monetizable" considerations regarding the economics of climate change strategies. As part of the cost/benefit discussion, the author contends that there are two fundamental ways to consider the Return on Investment (ROI) of climate-friendly investments, which he refers to as the 'micro' and the 'macro'. The question with regard to micro ROI is: Does it pay for itself in a reasonable amount of time and with what risks? The macro ROI plays out its effects on an entire economy (local, national, or global) and usually requires estimating the social costs of carbon (SCC). Two analyses of micro ROI are examined: (1) a study conducted by McKinsey & Co. for the Conference Board in 2007 and (2) Project Downsize in 2017. Both micro ROI analyses reveal that many solutions with major climate mitigation impacts are very cost-effective now. Macro studies begin with Nordhaus' DICE model. An important tool for a macro study is calculating the SCC, as it provides an economic rationale for making climate-related expenditures that do not exhibit a positive micro ROI. The SCC can be defined as:

"…the economic cost associated with climate damage (or benefit) that results from the emission of an additional tonne of carbon dioxide (tCO_2)."

The author relates the U.S. National Academies of Science's description of the commonly used, four-step integrated assessment model (IAM) for estimating the SCC. An important determinant of the viability of any macro ROI is the scope, that is, the boundaries within which data is collected and examined. The U.S. government is dramatically reducing the SCC calculations by including only costs to the U.S. rather than global impacts. A similar but different economic calculation is the price of carbon which, like SCC, varies according to the model and scenario used. It assumes diminishing returns, since the most favorable emissions are reduced first. Mr. Juniper thoroughly examines opposing opinions, those that: (1) favor a 'wait and see' attitude with regard to climate change actions, often referred to as Business As Usual or BAU and (2) subscribe to an 'act now' perspective. In 2018, Julian Morris of The Reason Foundation assembled an argument in support of BAU. Those in favor of acting now include:

1. UN Secretary-General (2018);
2. UN Green Industrial Policy (2017);
3. Risky Business Project (2016);
4. World Resources Institute (2014);
5. International Energy Agency (2011);
6. Australian National University's Centre for Climate Economics and Policy (2015); and
7. UN IPCC (2018).

Each of these positions is substantiated by the author. Another interesting concept explained by Mr. Juniper is 'discounting' which can have a major influence on the SCC. Discounting the value of future costs and benefits of projects with multi-generational impacts, for instance, dam construction,[15] is accepted as a rational "discounted utilitarianism" approach, but is justifiably controversial in its effect: that the future does not count for very much today. The cost of GHG removal is also discussed, for example, carbon sequestration. Negative emission technologies (NETs) and bio-energy with carbon capture and sequestration (BECCS) are part of that discussion. Illustrations of non-monetizable considerations include

[15] See chapter six, *Ecological and Infectious Disease Impacts of Hydropower in Sub-Saharan Africa* by B. Taylor in, **Demystifying Climate Risk Volume I: Environmental, Health, and Societal Implications** (LeBlanc, C. ed., Cambridge Scholars Publishing, 2017) for just such an example.

environmental/social justice and energy/national security. Quoting the author,

> "Our future is too important to be left to either wildly imperfect prices, and/or markets not designed to address this problem, and/or misplaced technological optimism."

constitutes a fitting end to this chapter.

Chapter Twelve: *The Role of Ethics and Governance in the Pursuit of Climate Science*, by Dr. Carole LeBlanc, is a departure from the author's previous writings as well the book's other sections. Perhaps the most consequential outcome of the chapter is the development by Dr. LeBlanc of *Ten Principles of Climate Action for Citizen Advocates* (condensed):

1. Join forces with a group involved with climate change;
2. Reward 'green' companies with your business;
3. Practice what you preach by reducing your plastic consumption;
4. Volunteer in climate action;
5. Find out if your place of work has a position or interest in climate change;
6. Take a course on climate change;
7. Help ensure that children's education includes climate change from an early age;
8. Consider a career path in a climate-related discipline;
9. Determine if the religious community to which you belong has a position on climate change; and
10. VOTE in every election, and know the candidates' positions on climate change before you do.

The principles were drafted as a result of the dramatic climate change data reported in this book and elsewhere, and the author's own personal experiences as a former federal- and state-government official, teacher, and involved citizen.

SECTION I.

CONCERNING SCIENCE

CHAPTER ONE

ASSESSING THE SCIENCE OF CLIMATE CHANGE

DONALD J. WUEBBLES, PH.D.[1]

Introduction

On November 3, 2017, the United States government, through the United States Global Change Research Program released Volume I of the 4th National Climate Assessment. This report, called the Climate Science Special Report or CSSR, is an authoritative assessment of the science of climate change, with a focus on the United States (USGCRP, 2018). It serves as the scientific foundation for Volume II of NCA4, which is an assessment of climate-related impacts, risks, and adaptation in the United States Volume II is scheduled for release in late 2018.

Over 50 scientists and other experts contributed to the writing of the CSSR assessment, including representatives from the United States government, national laboratories, universities, and the private sector. These experts were chosen by a steering committee led by major United States government agencies. The CSSR was subjected to many extensive reviews, by the scientific community and general public, by an external expert review

[1] Donald J. Wuebbles is the Harry E. Preble Professor of Atmospheric Science at the University of Illinois where he has been since 1994. He is also a Presidential Fellow at the University of Illinois, with the aim of helping the university system develop new initiatives in urban sustainability. An expert in atmospheric chemistry and physics, Dr. Wuebbles was awarded the Nobel Peace Prize in 2007 for his contribution to the Intergovernmental Panel on Climate Change (IPCC) assessment. Over his illustrious career, Dr. Wuebbles has published over 500 scientific papers related to the Earth's climate, air quality, and the stratospheric ozone layer and has received many awards. He has two degrees in electrical engineering from the University of Illinois (1970, 1972) and a doctorate in atmospheric sciences from the University of California, Davis (1983).

panel convened by the National Academy of Sciences, and through multiple reviews by federal agencies.

Our analyses have shown that new observations and new research have increased our understanding of past, current, and future climate change since the Third United States National Climate Assessment (NCA3) was published in May 2014. Over the last 4 years since the 3rd NCA, stronger evidence has emerged for the ongoing, rapid, human-caused warming of the global atmosphere and ocean. Researchers can also now more closely pinpoint the human influences for individual climate and weather extreme events. Key findings from the 4th NCA (USGCRP, 2017) are presented in this chapter, along with a few results from prior studies, especially in a look at impacts from climate change, and a few new findings based on recently published research.

Temperature and other indicators of climate change

Global, annually averaged, surface air temperature has increased by about 1.8°F (1.0°C) over the last 115 years (1901-2016). The change in temperature for the continental United States for period is also 1.8°F. This period is now the warmest in the history of modern civilization. The last few years have also seen record-breaking, climate-related weather extremes, and the last three years have been the warmest years on record for the globe (Fig. 1.1). These trends are expected to continue over climate timescales.

Many other aspects of global climate are changing. Thousands of studies conducted by researchers around the world have documented changes in a diverse array of important parameters, including surface, atmospheric, and oceanic temperatures, melting glaciers, diminishing snow cover, shrinking sea ice, rising sea levels, and ocean acidification[2]. The ocean heat content is increasing, with over 90% of the additional heat coming from the increasing levels of carbon dioxide (CO_2) and other greenhouse gases (GHGs) going into the oceans. As expected from basic physics, rising temperatures are leading to an increasing global amount of atmospheric water vapor.

[2] Ocean acidification is the ongoing decrease in the pH of the Earth's oceans caused by the uptake of carbon dioxide from the atmosphere, seawater being slightly basic.

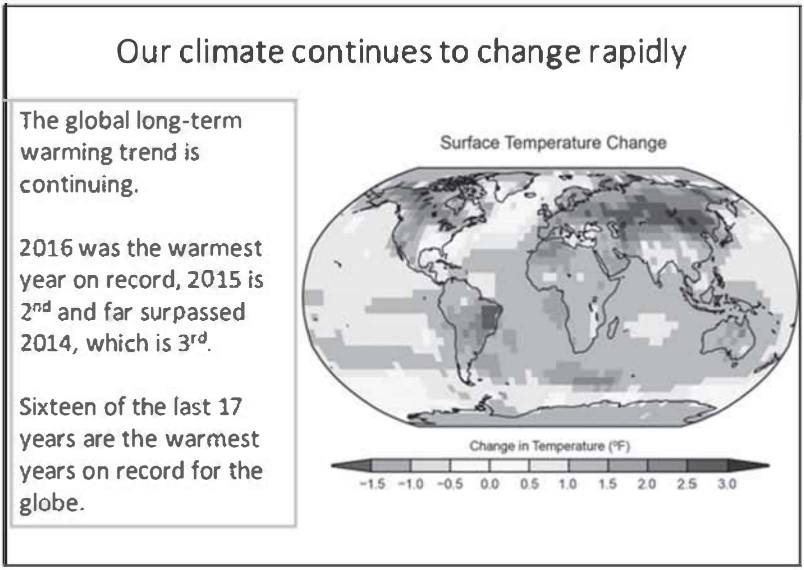

Fig. 1.1. Temperature trends (change in °F) for the period 1986-2015 relative to 1901-1960 (USGCRP, 2017)

Extreme weather events

Changes in the characteristics of extreme events are particularly important for human safety, infrastructure, agriculture, water quality and quantity, and natural ecosystems. Some extremes have already become more frequent, intense, or of longer duration, and many extremes are expected to continue to increase or worsen, presenting substantial challenges.

Now let's discuss the findings from the CSSR (and more recent studies) about some of the key types of extreme events:

Larger precipitation events. Heavy precipitation, as either rainfall or snowfall, is increasing in intensity and frequency across the United States and globally and is expected to continue to increase. The largest observed changes in extreme precipitation in the United States have occurred in the Northeast and the Midwest. Recent analyses also point to a likely increase in dry days and low precipitation days over much of the United States while the number of days of extreme precipitation is likely to increase (Zobel et al.,2018).

Heat waves. Heat waves (multi-day, usually 5-7 days or longer, periods of unusually high temperatures) have become more frequent in the United States since the 1960s, while extreme cold temperatures and cold waves have become less frequent. Around the world, heat waves have increased since 1900. Recent record-setting warm years are projected to become much more common in the coming decades over the United States, as annual average temperatures continue to rise (Fig. 1.2).

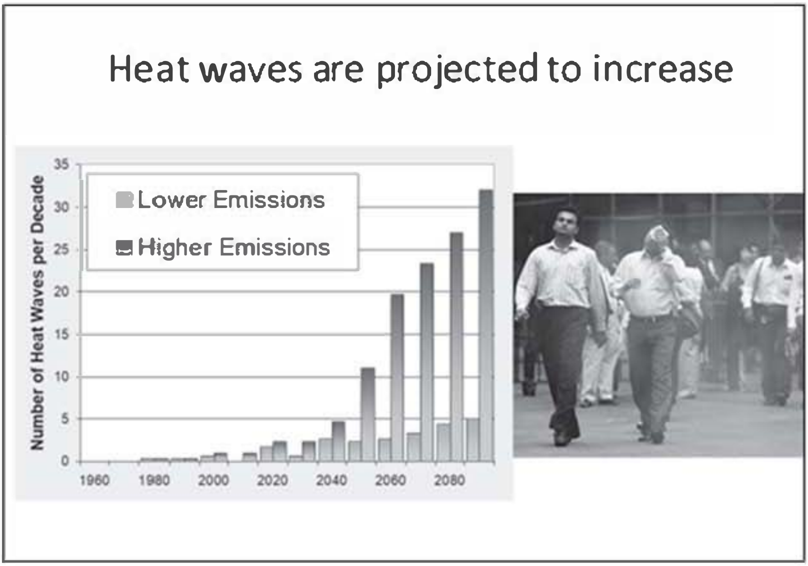

Fig. 1.2. Chicago, Illinois (United States) 1995-type heat wave will become routine by end of century – as many as 3 per year by 2100 (Wuebbles et al., 2010)

Drought. Annual trends toward earlier spring snowmelt and reduced snowpack are already affecting water resources in the western United States, with adverse effects for fisheries and electricity generation. These trends are expected to continue. Under the highest emissions scenarios, and assuming no change to current water resources management, chronic, long-duration hydrological drought is increasingly possible before the end of this century (Fig. 1.3).

Recent droughts and associated heat waves have reached record intensity in some United States regions. At this time, the report notes that evaluating the human effect on recent major United States droughts is uncertain. Little evidence is found for a human influence on observed precipitation deficits, but much evidence is found for a human influence on surface soil moisture deficits due to increased evapotranspiration caused by higher temperatures.

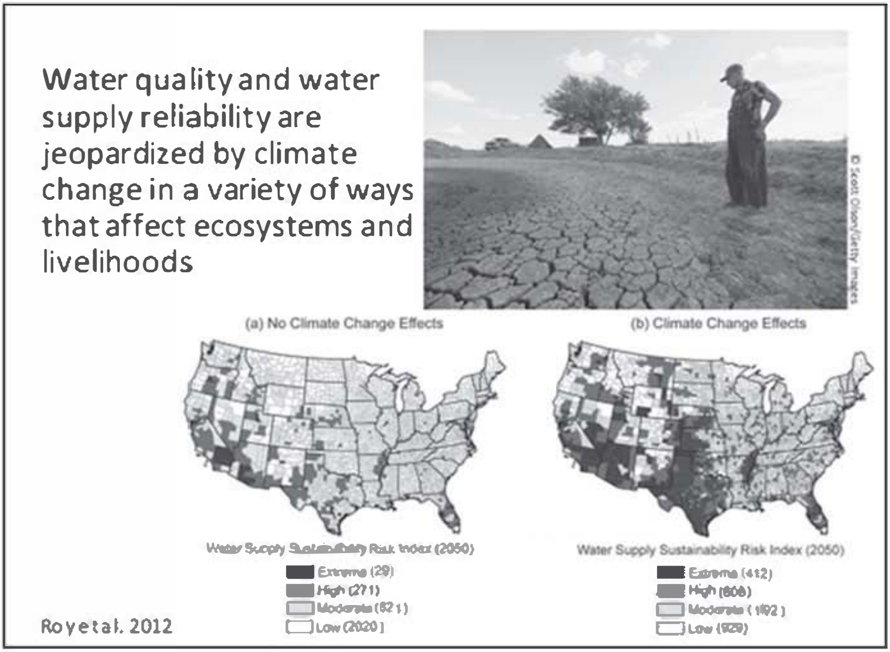

Fig. 1.3. Water supplies are projected to decline due to climate change (Roy et al., 2012)

Forest fires. The incidence of large forest fires in the western contiguous United States and Alaska has increased since the early 1980s and is projected to further increase in those regions as the climate warms, with profound changes to regional ecosystems. The frequency of large wildfires is influenced by a complex combination of natural and human factors.

Atmospheric rivers. Atmospheric rivers are narrow streams of moisture that account for 30-40% of the typical snowpack and annual precipitation on the United States West Coast. They are also associated with severe flooding events when they shed their moisture quickly or in vulnerable regions. The frequency and severity of landfalling atmospheric rivers will likely increase because rising temperatures result in higher atmospheric water vapor concentrations.

Hurricanes. Physical processes suggest, and numerical modeling simulations generally confirm, an increase in the intensity of hurricanes, also known as tropical cyclones, in a warmer world, and Earth system models generally show an increase in the number of very intense tropical cyclones. For Atlantic and eastern North Pacific hurricanes, increases are projected in precipitation rates and intensity. The frequency of the most intense of these storms is projected to increase in the Atlantic and western North Pacific and in the eastern North Pacific.

New studies since CSSR suggest that recent intense hurricanes like Harvey were significantly affected by the changes that have already occurred in climate (Emanuel, 2017; Risser and Wehner, 2017; van Oldenberg et al., 2017).

More generally, what's striking here is that events that we consider to be extreme may become the new normal by century's end.

Sea level rise

Global average sea level has risen by about 7-8 inches since 1900, with almost half (about 3 inches) of that rise occurring since 1993. Human-caused climate change has made a substantial contribution to this rise since 1900, contributing to a rate of rise that is greater than during any preceding century in at least 2,800 years. Global sea level rise is already affecting the United States; for example, the incidence of daily tidal flooding is accelerating in more than 25 Atlantic and Gulf Coast cities.

Global average sea levels are expected to continue to rise – by at least several inches in the next 15 years and by 1 to 4 feet by 2100. A rise of as much as 8 feet by 2100 cannot be ruled out. Sea level rise is expected to be higher than the global average in some parts of the United States, especially on the East and Gulf Coasts of the United States.

Climate change is largely happening because of human activities

Recent data add to the weight of evidence for rapid global-scale warming, the dominance of human causes, and the expected continuation of increasing temperatures, including more record-setting extremes.

Many lines of evidence demonstrate that it is extremely likely that human influence has been the dominant cause of the observed warming since the mid-20th century. Over the last century, there are no convincing alternative explanations supported by the extent of the observational evidence. Solar output changes and internal natural variability contribute only marginally to the observed changes in climate over the last century, and there is no convincing evidence for natural cycles in the observational record that could explain the observed changes in climate.

The likely range of the human contribution to the global mean temperature increase over the period 1951-2010 is 1.1° to 1.4°F (0.6° to 0.8°C), and the central estimate of the observed warming of 1.2°F (0.65°C) lies within this range (high confidence). This suggests a substantial human contribution to the observed 1951-2010 change. The likely contributions of natural forcing and internal variability to global temperature change over that period are minor.

Projections of climate change

The magnitude of climate change beyond the next few decades will depend primarily on the amount of greenhouse gases (especially CO_2) emitted globally. Without major reductions in emissions, the increase in annual average global temperature relative to preindustrial times could reach 9°F (5°C) or more by the end of this century. With significant reductions in emissions, the increase in annually averaged global temperature could be limited to 3.6°F (2°C) or less.

The atmospheric CO_2 concentration is now over 400 parts per million (ppm) globally and annually averaged, a level that last occurred about 3 million years ago, when both global average temperature and sea level were significantly higher than today. Continued growth in CO_2 emissions over this century and beyond would lead to an atmospheric concentration not experienced in tens to hundreds of millions of years. There is broad consensus that the further and the faster the Earth system is pushed towards warming, the greater the risk of unanticipated changes and impacts, some of which are potentially large and irreversible (Fig. 1.4).

The observed increase in carbon emissions over the past 15-20 years has been consistent with higher emissions pathways. In 2014 and 2015, emission growth rates slowed as economic growth became less carbon-intensive. Even if this slowing trend continues, however, it is not yet at a rate that would limit global average temperature change to well below 3.6°F (2°C) above preindustrial levels.

Without significant cuts to emissions, annually averaged global temperatures will almost certainly rise beyond 2°C (or 3.6°F) by the end of the century, the amount generally accepted as an indication of major concern. On a more positive note, there are indeed emission pathways which enable the United States and the world to remain below 3.6°F (2°C) of warming. Almost all of these mitigation pathways, except those with the most-rapid near-term emission reductions, are heavily reliant on the implementation of CO_2 removal from the atmosphere later in the century or other climate intervention.

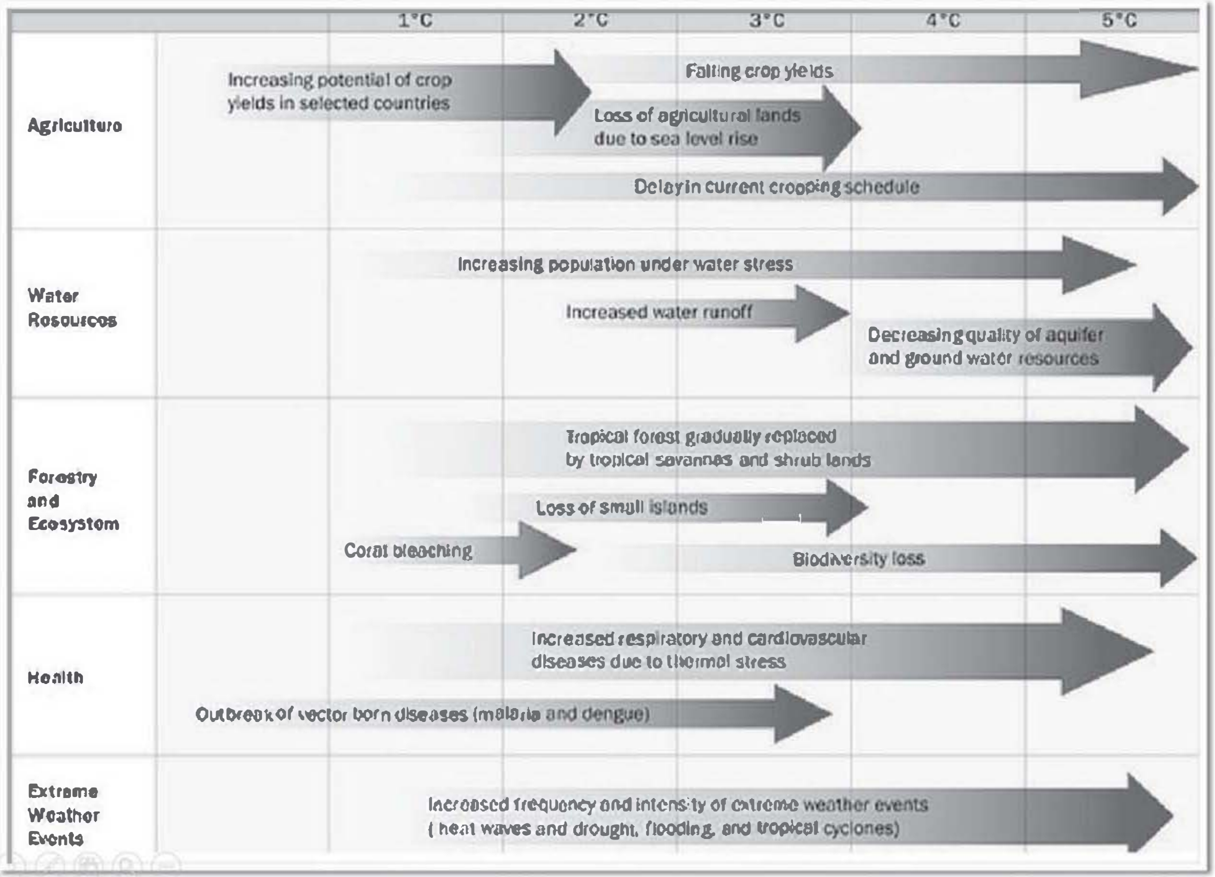

Fig. 1.4. Diverse risks increase with more climate change (based on Stern et al., 2006)

Current and potential impacts of the changing climate

The CSSR was devoted entirely to the science of climate change, not its impacts on humanity or on ecosystems. Those will be discussed in Volume II. However, many other studies, including the 3rd United States National Climate Assessment (Melillo et al., 2014) have discussed the current and potential impacts. That report included analyses of impacts on seven sectors human health, water, energy, transportation, agriculture, forests, and ecosystems and the interactions among sectors at the national level. The NCA aim is to help inform Americans' choices and decisions about investments, where to build and where to live, how to create safer communities and secure our own and our children's future. They found that ***impacts related to climate change are already evident in many sectors and are expected to become increasingly disruptive across the nation throughout this century and beyond*** (Fig. 1.5).

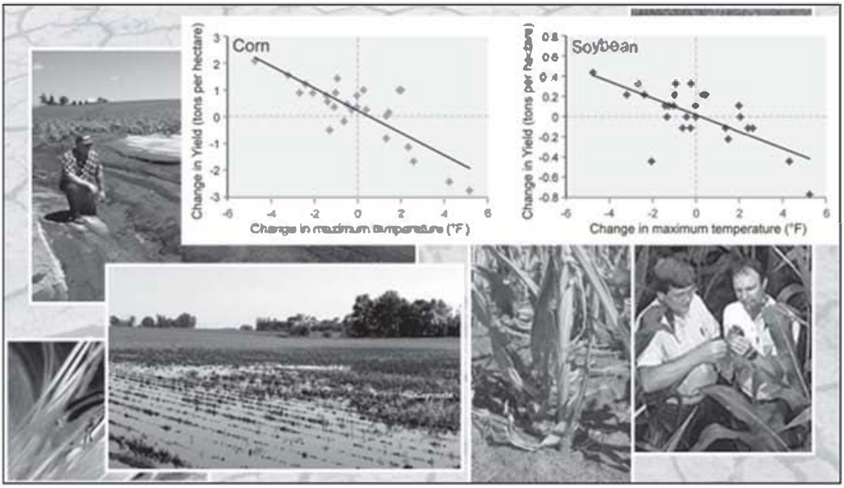

Fig. 1.5. The agriculture sector will experience longer growing seasons and more CO_2 but this sector will also face increasing challenges from heat stress, water stress, pests, diseases, and weather extremes (Melillo et al., 2014)

In summary, the 3rd NCA concluded: The observed warming and other climatic changes are triggering wide-ranging impacts in every region of our country and throughout our economy (Fig. 1.6). Some of these changes can be beneficial over the short run, such as a longer growing season in some regions and a longer shipping season on the Great Lakes. But many more are detrimental, largely because our society and its infrastructure were designed for the climate that we have had, not the rapidly changing climate we now have and can expect in the future. In addition, climate change does not occur in isolation. Rather, it is superimposed on other stresses, which combine to create new challenges.

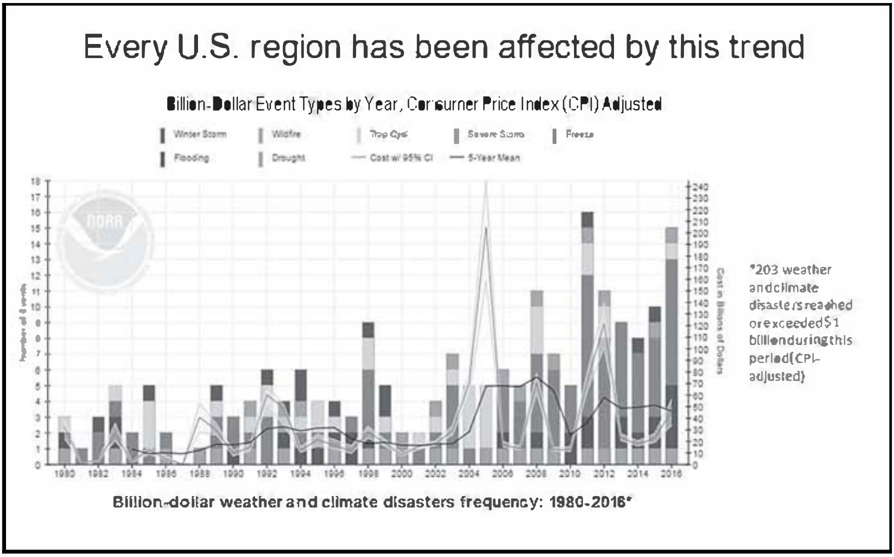

Fig. 1.6. Increasing effects of severe weather on the United States economy total $1.1 trillion since 1980 ($1.5 trillion if include 2017), according to the National Oceanic and Atmospheric Administration (NOAA)

Conclusion

In the discussion above, I have focused on the state of the scientific understanding of climate change based on the peer-reviewed literature as assessed in Volume I of the 4th National Climate Assessment. However, I want to end with a personal message that is based on my understanding of the science, the resulting impacts, and what these are telling us climate change is clearly one of the most important issues of our time. It is clearly an issue we need to be taking very seriously if we are going to avoid the worst of the potential impacts on our children and our grandchildren.

It is easy to be depressed by the projected changes in climate, but I want to leave you with a sense of hope. Mitigation by reducing emissions of the gases is necessary to avoid the worst of the potential changes in climate and adaptation will also be necessary. We can avoid the unmanageable and we can manage the unavoidable. It is our choice (Fig. 1.7). We just have to have the willpower. But the people of our planet have a long history of being problem solvers – we can do this.

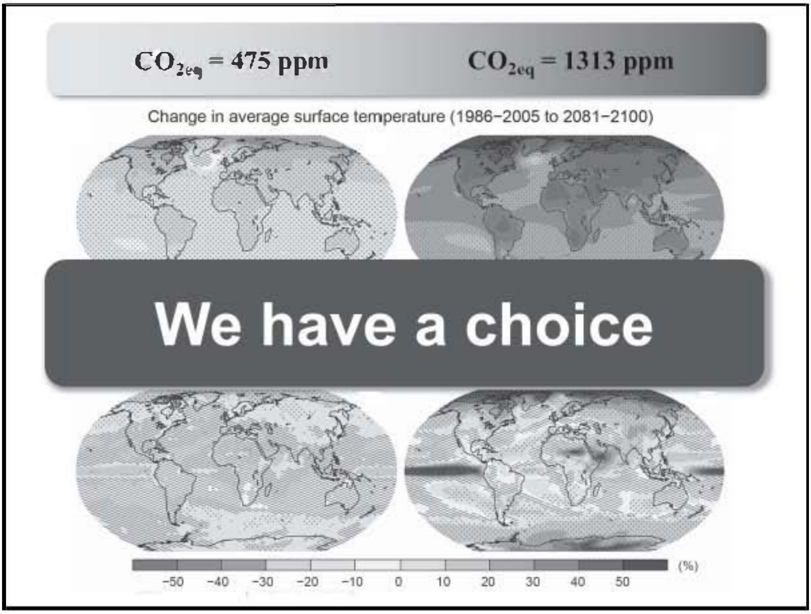

Fig. 1.7. Changes in average surface temperatures (top) and average precipitation (bottom) based on parts per million (ppm) atmospheric carbon, 1986-2005 and 2081-2100 (based on IPCC, 2013)

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CHAPTER TWO

TRACKING GLOBAL CHANGES IN GREENHOUSE GAS CONCENTRATIONS

STEPHEN A. MONTZKA, PH.D.[1]

Introduction

The Global Monitoring Division (GMD) of the United States (U.S.) National Oceanic and Atmospheric Administration (NOAA) Earth System Research Laboratory (ESRL) conducts research that addresses three major areas in atmospheric research:

- Greenhouse gases (GHG) and carbon cycle feedbacks;
- Changes in clouds, aerosols, and surface radiation; and
- Recovery of stratospheric ozone.

GMD consists of four research groups that are involved in making and interpreting atmospheric observations: (1) Carbon Cycle and Greenhouse Gases (CCGG); (2) Halocarbons and other Atmospheric Trace Species (HATS); (3) Ozone and Water Vapor (OZWV); (4) Global Radiation and

[1] Stephen A. Montzka is a research chemist at NOAA responsible for ongoing global atmospheric measurements of 30 different trace gases that influence climate, stratospheric ozone, and air quality. The atmospheric records he has provided over the past 25+ years are integral to NOAA's Annual Greenhouse Gas Index and NOAA's Ozone-Depleting Gas Index, which are indices that track changes in global concentrations of climate-active and ozone-depleting gases. During his career, he has authored or co-authored over 160 peer-reviewed papers and has been lead author of chapters related to atmospheric composition change in several national and international assessment reports on ozone depletion and climate. In 2018, Dr. Montzka was named a Fellow of AGU, the American Geophysical Union. This honor is bestowed on only 0.1% of AGU members for any given year.

Aerosols (G-RAD). While most of the measurements from each group are made at many different locations, including collaborator and networking sites, GMD operates four baseline observatories that unite the research groups and serve as the backbone of the GMD observing system. GMD's research groups:

> "work together in developing and maintaining their observing networks and, especially, in understanding, interpreting, and publishing results."[2]

The purpose of this paper is to communicate NOAA's findings in tracking changes in global atmospheric concentrations of long-lived GHGs (LLGHGs) and the underlying implications of these measured changes.

The greenhouse effect

According to Schmidt et al., (2010), the main contributors to Earth's greenhouse effect are:

- Water vapor 50%
- Clouds 25%
- Carbon dioxide (CO_2) 20%
- Methane, nitrous oxide, halocarbons, ozone, etc. 5%

Natural processes emit carbon dioxide, methane, and nitrous oxide; they also lead to the presence of ozone in our atmosphere. The resulting "natural" atmospheric concentrations of these LLGHGs, along with associated "natural" levels of water vapor and clouds, account for most of Earth's greenhouse effect today. In the absence of the greenhouse effect, Earth's average temperature would be nearly 60° Fahrenheit (F) lower than it is today, or about 0° F or -18° Celsius (C). If this were the case, most water on Earth would be frozen and life as we know it would not exist.

Many human activities lead to emission of these LLGHGs (for example, the burning of fossil fuels emits CO_2), and, as a result, atmospheric concentrations of these gases are elevated substantially above natural levels. Elevated concentrations of LLGHGs result in the absorption of more infrared radiation, so that less escapes directly into space. This has resulted in warming of the planet since preindustrial times and is sometimes called the Enhanced Greenhouse Effect.

[2] https://www.esrl.noaa.gov/gmd/about/aboutgmd.html.

Atmospheric components like water vapor and clouds are different than the other main contributors to the greenhouse effect, because they are controlled by condensation and evaporation so are *not* long-lived. As a result, water vapor and clouds only respond to the conditions (e.g., temperature) set by LLGHGs, like CO_2, methane, etc. Hence, these short-lived substances are not considered to be the cause of climate change but are responding instead to changes in temperature, winds, weather, etc., induced by LLGHGs and, as a result, amplify the warming influence from the LLGHGs.

Measurements of atmospheric composition from ice cores, firn air (unconsolidated snow above glacier ice), and ongoing, global-scale atmospheric measurements have unequivocally shown that atmospheric concentrations of LLGHGs have increased above natural levels. Given that these concentration increases will have an effect on Earth's climate, the questions we must ask ourselves are:

- How quickly are atmospheric concentrations changing and why?
- How might they change in the future and can we manage that trajectory?
- How are they adding to climate warming?

NOAA's global air sampling network

NOAA's Global Monitoring Division in Boulder, Colorado, U.S., maintains a vast cooperative air sampling network of nearly 90 sites around the world, from the northern tip of Alaska to the Gobi Desert in Mongolia and even to the snowy desolate landscape of the Antarctic South Pole (Fig. 2.1). At most of these sites, measurements are made of the most abundant greenhouse gases: CO_2, CH_4, and N_2O. From a portion of this network, measurements are made of long-lived halocarbons that are also potent GHGs. The goal of these efforts within NOAA-GMD is to map LLGHG concentrations throughout the lower atmosphere of the entire world.

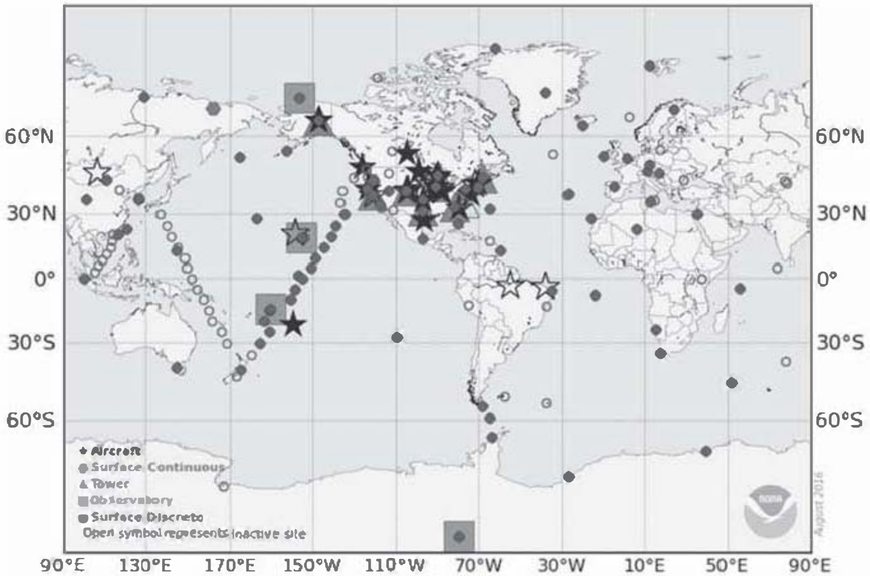

Fig. 2.1. NOAA network locations where measurements are taken of gases affecting climate, stratospheric ozone, and air quality over time.

Since the 1970s, sampling flasks have been filled weekly and then sent to the facility in Boulder where they are analyzed on multiple instruments. While the initial program enabled the measurements of only a few gases, these programs today provide measurements of over 40 long-lived chemicals and isotopologues[3] (e.g., $^{13}CO_2$). The emphasis of these efforts is on long-lived gases (gases having lifetimes of ~1 year or longer), as they are the largest contributors to climate warming today and whose impacts will be felt for decades and even centuries after being emitted (Fig. 2.2).

[3] An isotopologue of a chemical species has at least one atom with a different number of neutrons than the parent chemical.

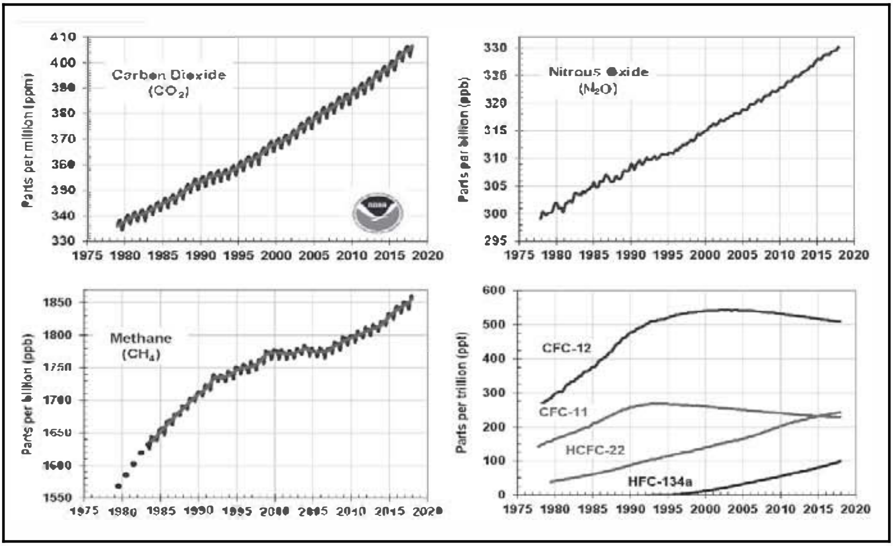

Fig. 2.2. Global mean surface concentrations measured for atmospheric carbon dioxide, nitrous oxide, methane, and some halocarbons [chlorofluorocarbon-11 and -12, (CFCs), hydrochlorofluorocarbon-22 (HCFC-22), and hydrofluorocarbon-134a (HFC-134a)], 1975-2017 (figure at: https://www.esrl.noaa.gov/gmd/aggi/aggi.html, and data are available at: https://www.esrl.noaa.gov/gmd/dv/ftpdata.html). For CO_2 and CH_4, the jagged line represents monthly means, while the smooth lines are the running annual mean in which seasonal variations have been averaged out. For methane, the oldest results (points in 1979 - 1983) are derived from measurements from an air archive, and air trapped in Antarctic snow (firn) and ice (Etheridge et al., 1998).

Overall climate influence of changes in gas concentrations

Not all trace gases influence climate similarly. The influence of a trace gas on climate depends on its:

- Efficiency for absorbing available heat energy (Fig. 2.3 and 2.4);
- Concentration in the atmosphere (Fig. 2.4 provides examples of radiative efficiencies and concentrations for certain gases); and
- Persistence in the atmosphere (Table 2.1 and Fig. 2.5). The persistence, or lifetime, of a trace gas is important because climate responds to the cumulative heat trapped by a trace gas over time.

The effect of a trace gas on the energy balance of Earth's climate system can be expressed as a radiative forcing. The Intergovernmental Panel on Climate Change (IPCC) Fourth Assessment Report (AR4; IPCC, 2007) defines radiative forcing as:

> "A measure of the influence a factor has in altering the balance of incoming and outgoing energy in the Earth-atmosphere system and is an index of the importance of the factor as a potential climate change mechanism."

Radiative forcing is expressed in watts (W) per square meter (m^2), which is equivalent to energy per unit time per surface area. For gases at low concentrations, radiative forcing is estimated by multiplying their radiative efficiency by their global atmospheric concentration (i.e., by multiplying the dark bars by the light bars in Fig. 2.4). For gases at higher concentration (CO_2, CH_4, N_2O), however, radiative forcing is non-linearly related to atmospheric concentration (Ramaswamy et al., 2001).

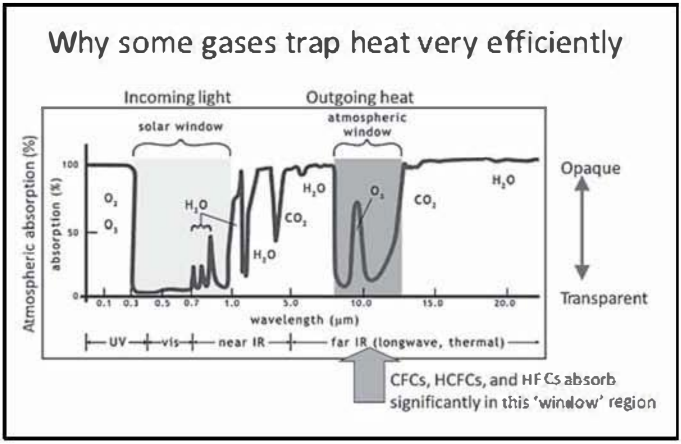

Fig. 2.3. The absorption of energy (light and heat) by Earth's atmosphere as a function of the wavelength of that energy. Incoming visible light with wavelengths in the "solar window" region (lighter shaded region) are transmitted through the atmosphere to Earth's surface without being absorbed substantially. Heat (infrared energy) being re-radiated from Earth's surface with wavelengths in the "atmospheric window" region (darker shaded region) mostly escapes to space. Gases that absorb heat energy with wavelengths in this "atmospheric window" region are potent GHGs because they absorb heat that would otherwise escape to space.
Note: Given current atmospheric concentrations, an additional molecule of CFC, HCFC, or HFC absorbs heat re-radiated from Earth's surface much more efficiently (by factors of 25 to 10,000) than an added molecule of CO_2 (see Fig. 2.4) (IPCC, 2007).

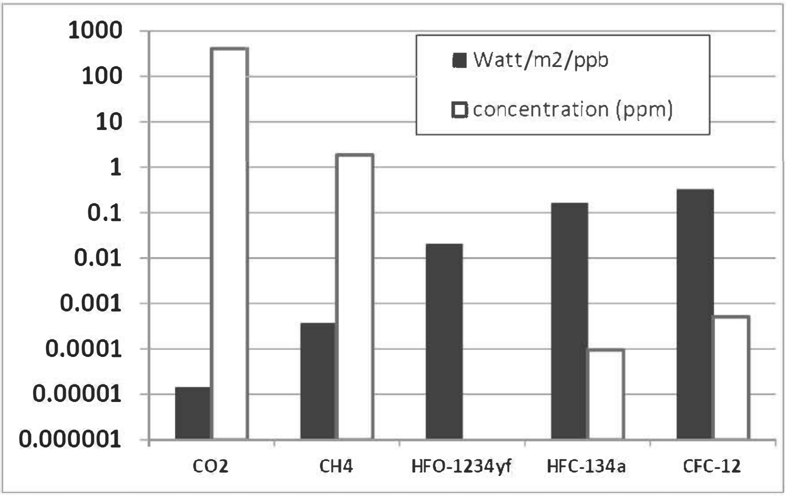

Fig. 2.4. The wide range of measured concentrations and heat-trapping efficiencies (i.e., radiative efficiencies) of some LLGHGs present in the atmosphere today (note log scale). The heat-trapping efficiency of these gases (dark bars) is expressed as the heat absorbed per unit concentration, or Watt/m^2/ppb, where ppb refers to concentration in parts per billion. Ambient global mean surface concentrations (light bars) measured by NOAA-GMD in recent years are expressed in parts per million (ppm) (note that 1 ppm = 1000 ppb and the global mean concentration of HFO-1234yf is too low to be visible on this scale).

Table 2.1. Natural processes irreversibly remove GHGs from the atmosphere at different rates

Atmospheric persistence (as lifetime) in years	
CO_2	100 to >1000*
CH_4	10
HFO-1234yf	0.03
HFC-134a	14
CFC-12	100

*Not a single timescale, as 20-60% remains airborne for > 1,000 years (Archer and Brovkin, 2008).

The term lifetime is similar to the term "half life" as applied to the decay of radioactivity from nucleotides over time. Atmospheric lifetime, however, refers to the time it would take for the global atmospheric concentration of a trace gas arising from a pulse emission to decrease to 1/e (or 1/2.718, or 37%) of its initial concentration.

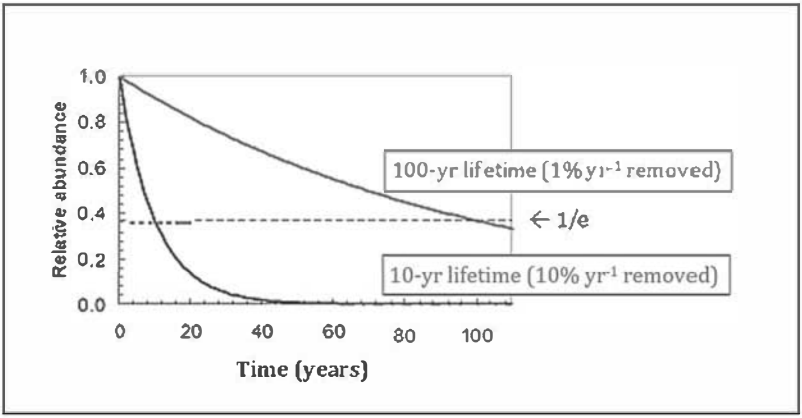

Fig. 2.5. Timescales for atmospheric removal of a pulsed emission of two gases having different lifetimes (10 years and 100 years).

Given today's measured global atmospheric concentrations, we can estimate the radiative forcing being supplied by LLGHGs and how that forcing has changed in the past (Fig. 2.6). This radiative forcing reflects the net result of past emissions and natural removal processes.

This analysis reveals that carbon dioxide accounts for 2/3 of the current atmospheric radiative forcing from all LLGHGs and > 80% of the increase in radiative forcing over the past 5 years from all LLGHGs (Fig. 2.6). Furthermore, *the overall increase in radiative forcing from 2015 to 2016 was the second largest annual increase on record (https://www.esrl.noaa.gov/gmd/aggi/aggi.html)*.

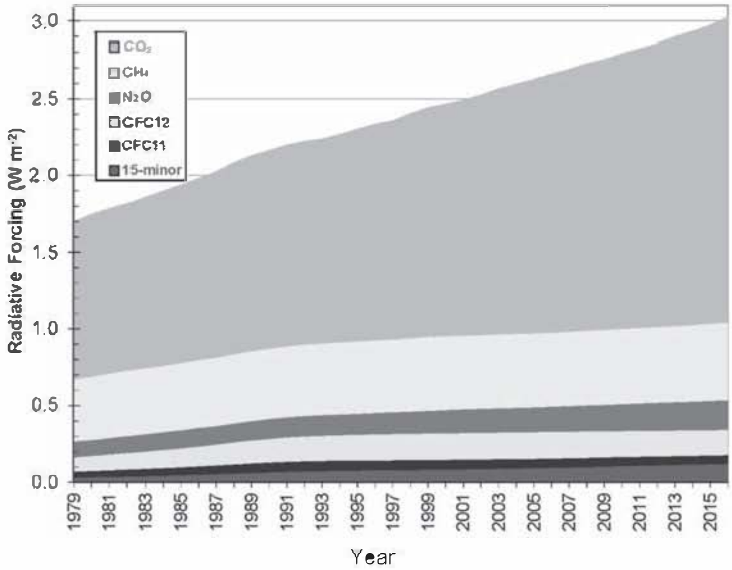

Fig. 2.6. Recent changes in the radiative forcing (or warming influence) supplied by measured changes in global surface concentrations of LLGHGs. For reference, climate sensitivity at equilibrium is thought to be 0.5-1.2°C/ (W/m^2) (Hansen et al., 2007). Note: 3 W/m^2 is equivalent to 1.2% of the net energy Earth absorbs from the Sun (Hansen et al., 2007), or the heat from 14 trillion 100-watt lightbulbs evenly distributed across Earth's surface (that's one bulb every 20 ft x 20 ft, that is always on).

NOAA's Annual Greenhouse Gas Index (AGGI)

"The AGGI is a measure of the climate-warming influence of long-lived trace gases and how that influence has changed since the onset of the industrial revolution. The index was designed to enhance the connection between scientists and society by providing a normalized standard that can be easily understood and followed. The warming influence of LLGHGs is well understood by scientists and has been reported by NOAA... Nevertheless, the language of scientists often eludes policy makers, educators, and the general public. This index is designed to help bridge that gap. The AGGI provides a way for this warming influence to be presented as a simple index."[4]

[4] https://www.esrl.noaa.gov/gmd/aggi/.

The AGGI is derived directly from the measure of radiative forcing from LLGHGs over time and reflects only post-industrial changes, mainly from humans, and not warming from natural sources of these gases (Hofmann et al., 2006). Its value in a given year reflects the warming influence (or radiative forcing) in that year relative to 1990, based on atmospheric changes since 1750 (Fig. 2.7). The value for the AGGI in 2017 of 1.41 means that the warming influence from human-derived emissions of LLGHGs has increased by 41% since 1990.

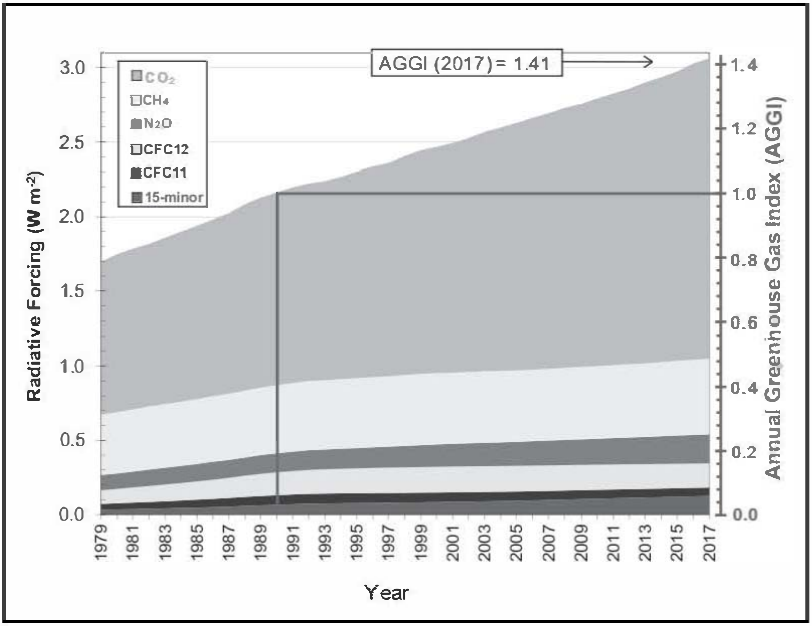

Fig. 2.7. Deriving NOAA's AGGI from radiative forcing: The increase since 1990 is ~0.9 W/m^2.

Deriving global emission rates from atmospheric data

Radiative forcing provides an estimate of the warming influence being supplied by a LLGHG at a point in time as a result of emissions in the past. It does not, however, indicate how the warming influence from these gases will change in the *future*. The future of climate warming will reflect both the persistence of GHGs in the atmosphere today (their lifetimes) as well as the magnitude and persistence of current GHG emissions. To understand how the current mix of trace gas emissions and the magnitude of those emissions might influence radiative forcing and climate in the future, we need to be able to estimate global emission magnitudes for the LLGHGs.

The global emission rate of a long-lived trace gas can be calculated from its global atmospheric concentration and an understanding of its loss rates (or lifetime). Emission magnitudes are typically derived for non-CO_2 LLGHGs with mass balance considerations, that is:

Measured global concentration change = Emissions   Losses

Consequently, NOAA's measurements of global concentration and its change over time for non-CO_2 LLGHGs can provide an estimate of global emission magnitude for a trace gas when natural loss rates (or lifetimes) are also known. Emission magnitudes can be expressed as mass of the trace gas per unit time, or with a weighting factor that allows the warming influence of emissions of different gases to be considered on a common scale (CO_2-equivalents). The weighting factor used to derive CO_2-eq emissions is typically the Global Warming Potential (GWP) and represents the warming supplied by the emission of a trace gas relative to the warming supplied by an equivalent emission of CO_2, integrated over 100 years. CO_2-equivalent emission magnitudes can be derived for all LLGHGs by weighting (multiplying) their emission magnitude by their GWP. For the two non-CO_2 gases with substantial natural emissions (CH_4 and N_2O), the anthropogenic emission rate is derived by subtracting the preindustrial emission rate (derived from ice-core concentration measurements as a constant emission) from the total emission inferred with the mass balance approach described above.

A comparison of present-day anthropogenic CO_2-eq emissions of non-CO_2 gases derived with this approach reveals that: (1) CH_4 in the largest non-CO_2 contributor and N_2O is the second largest non-CO_2 contributor; (2) emissions of ozone depleting substances (ODSs) have declined substantially because of international controls under the Montreal Protocol for the protection of stratospheric ozone; and (3) emissions of HFCs are currently small but steadily increasing (Fig. 2.8).

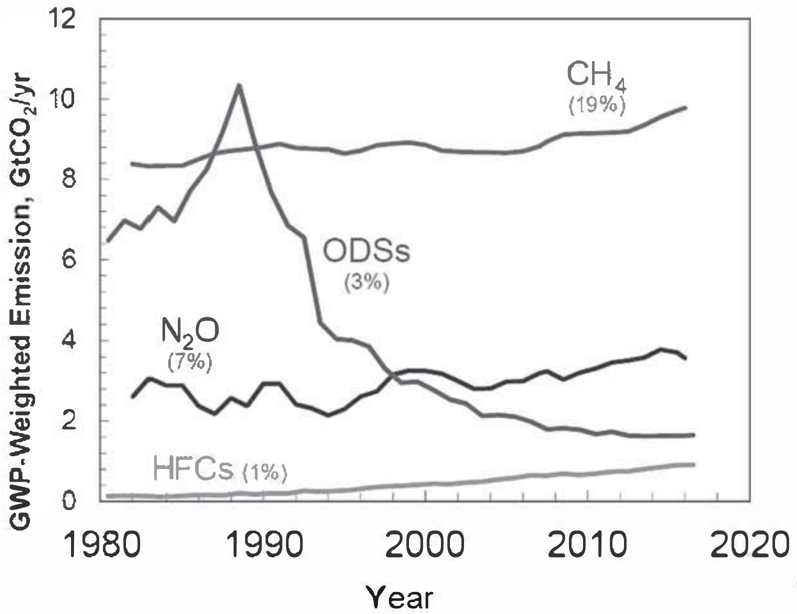

Fig. 2.8. Human (anthropogenic) emissions of non-CO_2 GHGs: CH_4, ODSs, N_2O and HFCs, 1980-2016, expressed as CO_2-eq. These emissions are derived from measured global atmospheric concentrations above preindustrial values and an understanding of natural loss processes (i.e., chemical lifetimes) (an update of analyses in Montzka et al., 2011).

The method described above for deriving global emission rates of LLGHGs works for non-CO_2 GHGs because natural loss processes for these gases are adequately described by a single time constant (or lifetime). Unfortunately, the irreversible atmospheric removal of CO_2 is not described simply; the irreversible removal rate of CO_2 depends on how long ago the emission occurred. As a result, we rely on global inventories of anthropogenic CO_2 emissions for estimating global anthropogenic emissions of this important LLGHG. Anthropogenic emissions of CO_2 in these inventories are primarily from global fossil fuel combustion and cement production (Friedlingstein et al., 2010;
https://www.bp.com/en/global/corporate/energy-economics/statistical-review-of-world-energy/co2-emissions.html).

A consideration of emissions of all significant LLGHGs reveals some significant points: (1) total anthropogenic emissions (as CO_2-eq) from the sum of all LLGHGs have increased since 1990 by 24%; (2) human-derived CO_2 emissions account for 70% of LLGHG emissions today, and they account for the largest increase in emissions in recent years (a 60% increase since 1990); and (3) emissions would be much higher without the Montreal Protocol controls (Fig. 2.9).

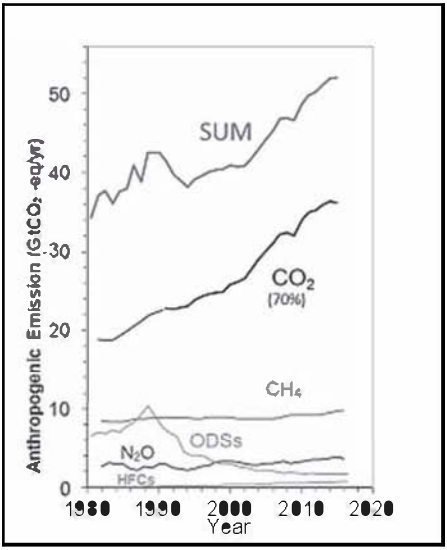

Fig. 2.9. Anthropogenic (i.e., human-caused) CO_2 and non-CO_2 GHG emissions, 1980-2016.

As a result of the magnitude and changes noted in the recent past for emissions of LLGHGs (Fig. 2.9), total radiative forcing from these gases has steadily increased over time (Fig. 2.5). Stabilizing climate will only be achieved by decreasing emissions of these gases to the point where radiative forcing stops increasing or even decreases. Given the dominant role for CO_2 in total radiative forcing and its recent increase, and in total GHG emission, any attempt to stabilize climate will have to focus on emissions of CO_2.

To what extent will climate (or radiative forcing) stabilize if we stop the increase in emission rates of LLGHGs? Answering this question depends critically on the atmospheric lifetime of a LLGHG, since only a small fraction of a long-lived gas is removed from the atmosphere each year. For example, only ~1% of the atmospheric burden of a trace gas having a 100-yr lifetime is removed each year (Fig. 2.5). The effective lifetime of CO_2 in today's atmosphere is much longer than 100 years, which means that CO_2 concentrations will not begin decreasing until emissions fall below this small natural removal rate. More specifically, emissions of CO_2 would need to decrease by 80% in order to stop the increase in its concentration and its associated radiative forcing (Fig. 2.10). *Just keeping CO_2 emissions constant in the future doesn't prevent a continued rapid increase in global warming from CO_2* (Fig. 2.10).

In contrast, non-CO_2 total radiative forcing from GHGs has increased fairly slowly over recent years. This is primarily because of three factors: 1) most of the non-CO_2 radiative forcing is from methane, 2) methane's lifetime is ~10 years, 3) and methane's sources and sinks are nearly in balance. This means that declines in the radiative forcing from methane could be realized with only relatively small decreases in emissions of methane (Fig. 2.10).

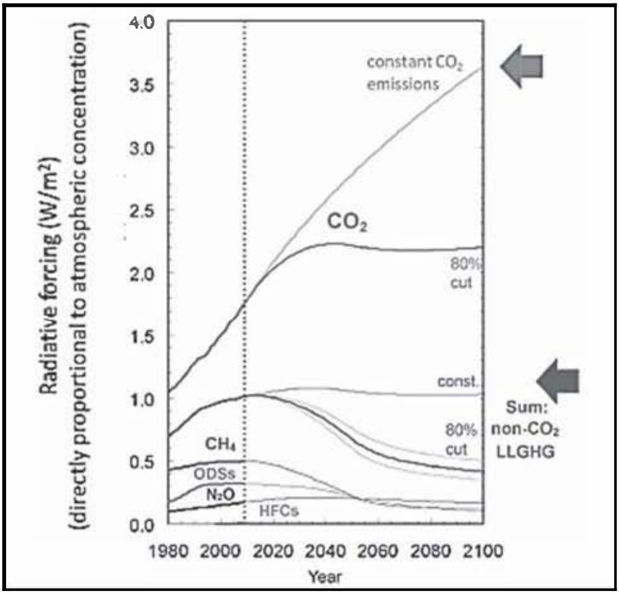

Fig. 2.10. The warming influence (radiative forcing) from CO_2 and non-CO_2 LLGHGs in the past based on measured atmospheric concentrations, and potentially in the future derived from concentrations calculated from either 1) constant emissions or 2) an 80% reduction in present-day emissions. Adapted from Montzka et al., 2011.

Ultimately, climate responds to overall radiative forcing, not just the forcing associated with one or two gases. These results compel us to ask: What is required to stop continued increases in the total warming influence of all LLGHGs? Select emission scenarios demonstrate the seriousness of our current situation if we hope to stop the continued increase in radiative forcing or enhanced warming from LLGHGs (Fig. 2.11).

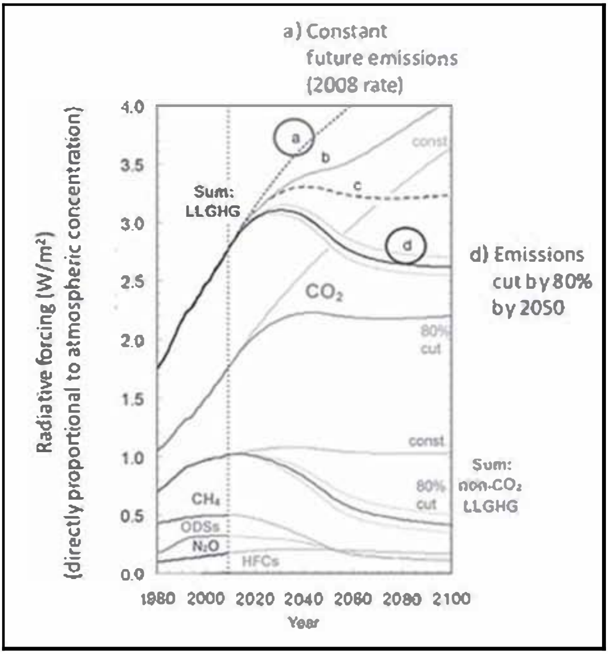

Fig. 2.11. The radiative forcing from measured and calculated LLGHG concentrations following different emission reduction scenarios in the future. The cuts in present-day emissions considered here were phased in at a steady rate and were complete by 2050. Scenarios considered a) constant emissions of all LLGHGs into the future at 2010 rates, b) constant future CO_2 emissions and an 80% decrease in non-CO_2 emissions by 2050, c) an 80% cut in CO_2 emissions phased in by 2050 and constant non-CO_2 GHG emissions, and d) an 80% cut in all GHG emissions relative to their 2010 emission level. For more information, see the work in which these scenarios were originally discussed (Montzka et al., 2011).

Results indicate that *anthropogenic warming by LLGHGs still continues to increase for several years after each of the emission reduction scenarios that is phased in gradually*. Even if emissions were cut by 80% by 2050, a decrease in radiative forcing from these gases would not be apparent until 2040 as concentrations levelled off. Furthermore, the results emphasize the necessity of targeting CO_2 emissions in any effort to stop the continued increase in radiative forcing and climate change. The human influence on climate will continue to become larger in the future (with more warming) unless CO_2 emissions coming primarily from fossil fuel combustion are reduced by 80%. One final note related to the relationship between climate and radiative forcing: the climate changes only slowly (i.e., with a time lag) in response to an increase in radiative forcing (Solomon et al., 2010). So any changes in climate observed to date do not reflect the full range of changes anticipated from the recent increases in radiative forcing.

Principles of climate protection

Global atmospheric observations of LLGHGs have several uses:

- They provide a measure of global atmospheric composition changes and of the radiative forcing being provided by that composition;
- They provide a measure of GHG emissions which enables identification of mitigation opportunities on global to local scales (Fig. 2.12); and
- They enable an assessment of efforts to stabilize climate warming on global scales.

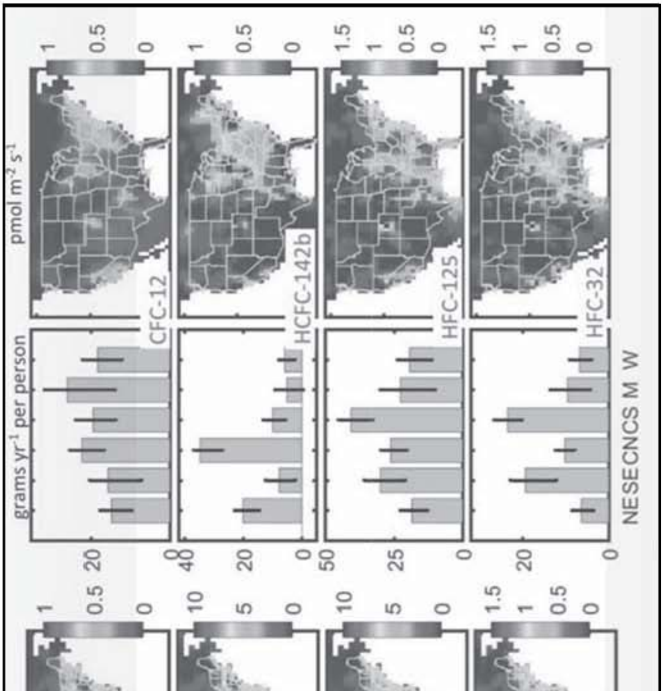

Fig. 2.12. Spatially-resolved emissions inferred from an analysis of measurements obtained from NOAA's U.S. atmospheric sampling network for a number of halogenated compounds that are potent LLGHGs (taken from Hu et al., 2017).

It is also true that emission rates of LLGHGs can be quantified on regional to continental scales using atmospheric observations. This effort requires relatively dense measurements in the region of interest, a good understanding of air transport in the region, and sophisticated data analysis tools. An example be found in NOAA's U.S.-wide atmospheric measurement network. Results from this approach identified a decline in U.S. GHG emissions over the past decade of ~0.6 Gigagram (Gg) CO_2/year (yr) for CO_2, CH_4, and N_2O (based on U.S. EPA inventory reporting) and a decline over the past decade of ~0.3 Gg CO_2/year for gases phased out by the Montreal Protocol (based on measurements in the U.S. sampling network; Hu et al., 2017) (Fig. 2.13).

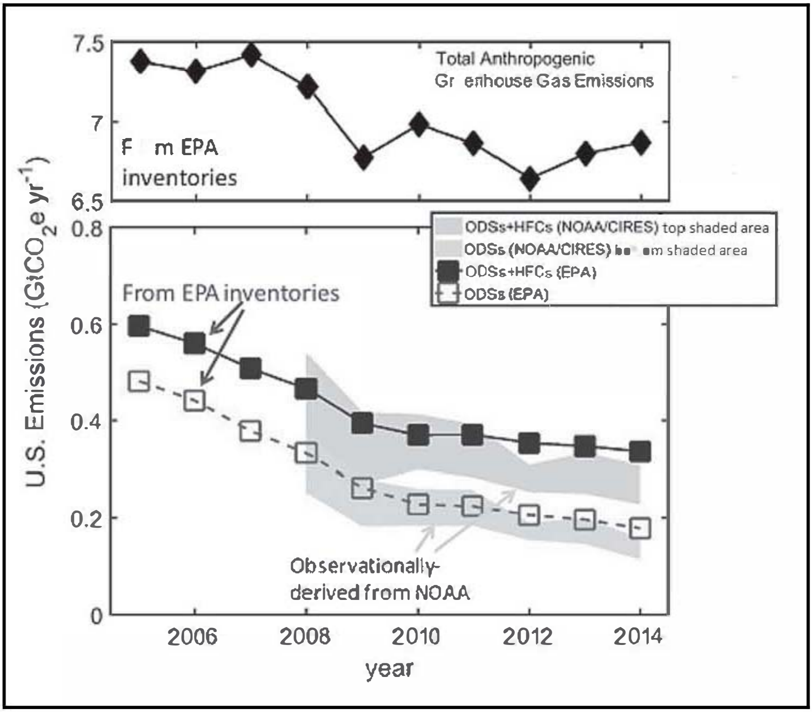

Fig. 2.13. Decreases in emissions of GHGs (top) and ODSs (bottom) in the U.S., 2004-2014 (Hu et al., 2017).

Conclusions

Since the 1990s and the Kyoto Protocol agreement, an international treaty which extends the United Nations Framework Convention on Climate Change (UNFCCC) that commits state parties to reduce LLGHG emissions:

- LLGHG emissions have instead increased by 24%;
- CO_2 emissions have increased by about 60% (inventory result); and
- Climate radiative forcing has increased 41% ($AGGI_{2017} = 1.41$), by 0.9 W/m^2.

Moreover, *the amount of warming supplied from LLGHGs is still increasing each year.*

To summarize:

- Climate warming from LLGHGs is proportional to their concentration and lifetime;
- Two-thirds of climate forcing and 70% of CO_2-eq emissions are currently from CO_2, a very long-lived gas; and
- Finally, stabilization of climate warming will require *large cuts* in emissions of CO_2 and other GHGs.

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CHAPTER THREE

A "4TH WAVE" PERSPECTIVE ON CLIMATE RISK MANAGEMENT

ISAMU 'SAM' HIGUCHI[1]

Abstract

The *"4th Wave" Perspective on Climate Risk Management* focuses on the advance technology business aspects of climate risk management. The "4th Wave" environmental movement is characterized by an emphasis on scarce resources, in particular, critical materials needed to manufacture innovative high technology products such as aerospace and electronic products. Business success and a nation's economic wellbeing depend on reliable supply chains to critical materials. These supply chains are vulnerable to natural disasters, including an increasing trend of climate change disruptions. To maintain their leadership positions, United States (U.S.) businesses and the nation need to manage climate-related risks, like supply chain disruptions. A business perspective climate risk management framework is proposed, based on a financial-accounting approach. A similar framework is proposed for a federal agency climate risk management framework, based on a statutory financial-accounting approach. U.S. businesses and the nation need to safeguard their assets to maintain their global leadership positions by managing their climate-related risks.

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Introduction

Historically, the environmental movement can be categorized by trends, “waves”. In 2009, Richard MacLean proposed the categorization of the environmental movement into waves. According to his categorization, we are currently just entering the “4th Environmental Wave” that focuses on “resources”. The prior wave categories included the “2nd Wave”, characterized as a period dominated by the promulgation of environmental regulations. Next was the “3rd Wave”, characterized as a period dominated by the concept of “sustainable development”. Now, we are witnessing the “4th Wave”, dominated by the focus on “resources;” more precisely stated by MacLean as “strategic resources positioning” (Table 3.1). This “4th Wave” is characterized by: (1) technical innovation and (2) control over scarce resources. Technology innovation depends on: (1) both critical key minerals and materials and (2) reliable supply chains.[1]

Table 3.1. Environmental movement, the “4th Wave”

Strategic resource positioning=Sustainable materials management (SMM)	
General characteristic	**“4th Wave” specific characteristic**
Focus:	Resources (e.g., critical materials need to develop new products)
Completive advantage:	Access to key resources (e.g., critical materials)
Output objective:	Innovation and creating advanced technologies products (e.g., incorporating critical materials)
Input objective:	Reliable supply chains (e.g., for raw critical materials)

There is strong evidence that we are currently in the “4th Wave”. In the U.S., two Executive Orders focus on aspects of the “4th Wave”. The first is Executive Order (EO) 13806, signed 21 July 2017, *Assessing and Strengthening the Manufacturing and Defense Industrial Base and Supply Chain Resiliency of the U.S.*[2] The second is EO 13817, signed 20 December 2017, *A Federal Strategy to Ensure Secure and Reliable Supplies of Critical Minerals*.[3] This “4th Wave” trend goes beyond the U.S.; it is global. The global trend evidence is provided by the European Union (EU) initiative publications such as, (1) *Critical Raw Materials and the Circular Economy*[4] and (2) *Raw Materials Information System* (RMIS)…[5] This “4th Wave” has profound significance to the U.S. and its continued global economic leadership.[6]

The "4th Wave" emphasis on "resources" and, more specifically, on "materials" has been expressed by others in three terms (Table 3.2): (1) "De-Carbonization", (2) "De-Materialization", and (3) "De-Toxification". More explicitly, "De-Carbonization" is focused on using less material-carbon energy fuels in manufacturing products to mitigate climate change. "De-Materialization" is focused on reducing "materials" in manufacturing products to conserve scarce material-minerals. Finally, "De-Toxification" is focused on eliminating toxic material-chemicals in manufacturing products to reduce environmental contamination. This emphasis on "materials", using these three terms, is characteristic of "sustainable materials management" (SMM).[7]

Table 3.2. Sustainable materials management (SMM) and climate change

SMM component	Comment
De-Carbonization:	Climate change mitigation by reducing greenhouse gas (GHG) emissions
De-Materialization:	Reduce GHG emissions by reducing energy required to refine materials (e.g., refining critical raw materials from minerals)
De-Toxification:	Reduce toxic chemical by-products, including ozone depleting substances (ODSs), that also are GHGs, from materials refining processes (e.g., release of toxic chemicals during the refining critical raw materials from minerals)

SMM has its importance in the manufacturing business sector of the economy. The manufacturing of advanced technology products requires critical raw minerals and materials that are in short supply globally. The scarcity of "critical minerals and metals" has been referred to as a "ticking time bomb" by management consulting firms. The management consulting firm of PricewaterhouseCoopers (PwC) has categorized this challenge of resource scarcity as SMM. Further, PwC defines the scope of this challenge as having three dimensions (Table 3.3): (1) physical (materials not accessible or reserves depleted), (2) economic (price volatility or market developments) and (3) geopolitical (export control/barriers or conflict zones).[8] The "physical dimension" is of interest, specifically, the aspect of materials that are not accessible. One of the most important reasons for materials not being accessible is due to natural disaster disruptions, especially natural disasters caused by increasing extreme weather and climate events.[9]

Table 3.3. Industrial manufacturing business and SMM

Materials scarcity	
Characteristic	**Manufacturing is disrupted when…**
Physical:	Materials not accessible–natural disasters
	Materials' reserves depleted–mining source has been completely consumed
Economic:	Price volatility–increases in price
	Market development–dominated by one or small number of consumers
Geopolitical:	Export control–stop or restrict export of materials
	Barriers or conflict zones–transport is hampered or cut

Significance of sustainable materials management and climate change

The relationship between SMM and increasing extreme weather and climate events is significant to our national economy and to U.S. businesses. Fundamentally, "materials", "energy", and "water" are all networked together; these three components are linked to each other and are all components of SMM.[10] The inter-connectiveness of "materials", "energy", and "water" (Fig. 3.1) means that a direct impact on one will result in impacts to the other two. "Materials", as an example, are vulnerable to climate change. Climate change can impact supply chains of materials through disruptions caused by extreme weather and climate events that are increasing. Further, these disruptions have a ripple effect on the competitive advantage of businesses and the financial-economic status of nations.

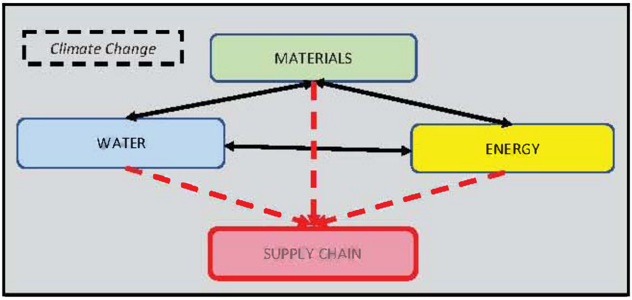

Fig. 3.1. Climate change: Materials, water, energy, and the supply chain

Up to this point the discussion has been very generalized, and it is appropriate to discuss these concepts in more specific terms. The U.S. has an overall negative trade balance. The U.S.' manufacturing of advance technology products in aerospace and electronics (including avionics) contribute positively to the nation's trade balance. If not for these two advance technology products, the nation's trade balance would be worse.[11] The aerospace manufacturing sector and the electronics manufacturing sector depend on access to critical minerals and materials for the creation on innovative advanced technology products. Maintaining global leadership in these two manufacturing sectors requires access to critical minerals and materials, and this means having reliable global supply chains for these critical minerals and materials.

For readers desiring more in-depth information on sustainable matters management they are referred to S. Happaerts' *International Discourses and Practices of Sustainable Materials Management*. The first 36 pages of this is publication provides an adequate brief overview of the subject.[12]

Business-management perspective: developing a climate risk framework

Businesses, and nations, must aggressively manage risks related to SMM if they want to maintain their competitive advantage. Considering the profound impact that extreme weather and climate events can have on business supply chains, it is entirely appropriate for businesses to seek to manage climate-related risks.

Developing a climate risk management framework for a business-management perspective has its generic beginnings in the concept of "enterprise risk management" (2004). In 2007, Lash and Wellington proposed a more specific risk management framework to address climate-related risks in their paper, *Competitive Advantage on a Warming Planet*. In 2008, the U.S. Environment Protection Agency (EPA) attempted to investigate a financial-accounting framework to management climate risks. The agency commissioned the study to investigate a financial-accounting framework, applying existing accounting standards for managing climate risks; the study was never released as a finalized publication.[13] Other documents on a business-management approach to managing climate-related risk include those by:

- U.S. Securities and Exchange Commission (SEC);
- Climate Disclosure Standards Board (CDSB);
- Sustainability Accounting Standards Board (SASB); and
- Task Force on Climate-related Financial Disclosure (TCFD).

All of these business-management climate-related risk management frameworks form a network (Fig. 3.2) and will be discussed in more detail, with the exception of the U.S. EPA study that was never finalized.

"Enterprise risk management" or ERM is the most widely accepted general risk framework by business-management professionals. In 2004, the authoritative framework, a two-volume publication set, was released by Committee of Sponsoring Organizations (COSO) of the Treadway Commission. ERM expanded beyond the area of financial internal control into non-financial risk related subject areas to improve an organization's performance. There are eight interrelated components to ERM:

- Internal environment;
- Objective setting;
- Event identification;
- Risk assessment;
- Risk response;
- Control activities;
- Information and communications; and
- Monitoring.[14]

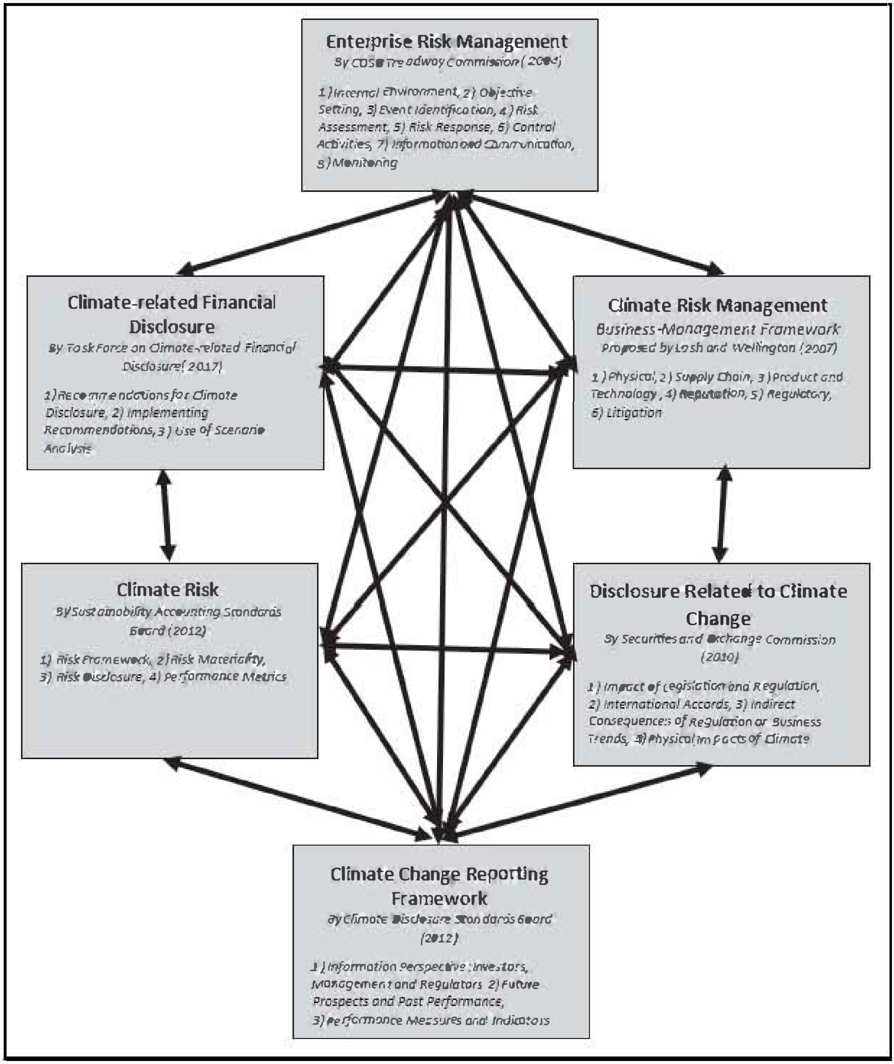

Fig. 3.2. Business-management perspective: Climate risk management framework

Overall, the ERM framework is generic, but it is broad enough in scope to include climate-related risks. Three of these components are especially important to managing climate-related risks: (1) event identification – includes external events (e.g., extreme weather and climate events such floods and drought), (2) risk assessment – management needs to analyze the likelihood and impact of the risk (e.g., disruption to supply chains from natural disasters), and (3) risk response – management needs to develop action to manage risks (e.g., climate-related risks).[15]

Lash and Wellington's 2007 framework is historically impressive because it provides a pattern for later climate-related risk frameworks. Their framework is composed of six climate-related elements. These climate-related risk components, listed in priority order of their significance to the "4th Wave" and SMM are:

- Physical risks;
- Supply chain;
- Product and technology;
- Reputation;
- Regulation; and
- Litigation.[16]

Physical climate-related risks are about damages to assets. Damages to assets are related to natural disasters caused by extreme weather and climate events associated with a changing climate. Supply chain climate-related risks are about disruptions; both upstream supply chain disruptions like sources of raw materials, and downstream disruptions like delivery of products or services to customers. At a very granular level, supply chains are a network of links and nodes; links are usually transport or transportation links. The product and technology climate-related risks are those risks associated with material scarcity challenges; these were detailed in the prior PwC discussion.

In 2010, the U.S. SEC released reporting guidance concerning climate change and its consequences. There are several component commonalities between the SEC guidance and the Lash and Wellington approach. The SEC identified several climate change-related components for information disclosure. These included: (1) impact of legislation and regulation, (2) international accords (e.g., Kyoto Protocol), (3) indirect consequences of regulation or business trends, and (4) physical impacts of climate change. The most relevant to the focus of this paper is "physical impacts". Specifically identified are:

> "[O]perations concentrated on coastlines, property damage and disruptions to operations, including manufacturing operations or the transport of manufactured products;

Indirect financial and operational impacts from disruptions to the operations of major customers or suppliers from severe weather, such as hurricanes or floods"

The SEC guidance's "conclusion" section includes a statement reminder to companies about their legal and regulatory obligations to disclose information relevant to decision making by investors.[17]

In 2012, the CDSB released its publication, *Climate Change Reporting Framework*. The reporting framework objective is to provide decision-useful information. This publication provides detailed reporting requirements for: (1) information from the perspective of: investors, management and regulators, (2) future prospects and past performance, and (3) performance measures and indicators. The goal of the reporting framework is to mainstream climate change-related disclosure reports. The reporting framework is a major initial step toward describing in detail decision-useful information if linking financial accounting and climate change.[18]

Another step towards linking financial accounting and climate change was the 2016 publication of SASB's, *Climate Risk – Technical Bulletin*. It is significant that the "foreword" of this publication was co-signed by Henry M. Paulson (74th Secretary of the U.S. Treasury) and Paul E. Rubin (70th Secretary of the U.S. Treasury) in a bipartisan unity focus on the financial importance of climate-related risks. Additionally, both Mr. Paulson and Mr. Rubin have links to the Risky Business Project that investigated U.S. economic risks presented by climate change. One of the most impressive features of the SASB publication is the section detailing industry-specific performance metrics, listing several specific metrics for each industry.[19] An example of the metrics for network resilience is presented in Table 3.4. The network resilience metrics are useful for cities, college campuses, military installations and federal facilities.

Table 3.4. Example of performance metrics for climate resilience

Performance metrics for:	Performance metric
Electrical grid Communications network Information network Water supply distribution system	1) Number of service disruptions 2) Population affected 3) Average duration
	1) Average interruption frequency 2) Average interruption duration
	1) Number of performance issues 2) Number of service disruptions 3) Number of days total customer downtime

In 2015, the G20 representing the 20 largest national economies of the world asked the Financial Stability Board (FSB) to study climate risk within the context of financial systems. The FSB established the TCFD to do the study, under the leadership of Michael R. Bloomberg. The TCFD completed its study in 2017, and submitted the study publications to G20 .[20] The study is composed of three major publications: (1) *Recommendations of the Task Force on Climate-related Financial Disclosure*, (2) *Implementing the Recommendations of the Task Force on Climate-related Financial Disclosure*, and (3) *The Use of Scenario Analysis in Disclosure of Climate-related Risk and Opportunities*.[21] Using the information in all three TCFD publications provides users with practice advice for gathering relevant information in doing financial disclosures. Internationally, the three TCFD publications move financial-accounting professionals closer to acceptable financial-accounting methods for standardization.

The third TCFD publication is particularly significant because it specifies applying two climate scenarios in the analysis: (1) high emissions scenario CMIP5 RCP8.5 and (2) low emissions scenario CMIP5 RCP 4.5.[2] The low emissions scenario is consistent with the Paris Agreement.[22] The high emissions scenario is consistent with current actual emissions pathway that the world is on.[23] This provides practical directions to users doing scenario analysis as part of their financial disclosure.

A business-management approach to a financial-accounting framework

Thus far, we have yet to investigate a business management approach to a financial-accounting framework for climate-related risks. The reader is referred to two noteworthy Australian publications related to climate risk management and financial-accounting approaches. The first is an academic publication, *Climate Change Adaptation in Industry and Business: A framework for best practice in financial risk assessment, governance and disclosure*.[24] The second publication is from a pragmatic perspective for implementing climate risk management within a business by the Australian Industry Group and the Department of Sustainability and Environment for Victoria, *Managing the Risks from Climate Change: An adaptation*

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[2] The Coupled Model Intercomparison Project (CMIP) is a collaborative framework designed to improve knowledge of climate change by the World Climate Research Programme's (WCRP). Representative Concentration Pathways (RCPs) are four GHG concentration (not emission) trajectories adopted by the Intergovernmental Panel on Climate Change (IPCC).

checklist for business.[25] These two publications provide the reader with additional detailed information concerning implementation of climate-related risk management and financial-accounting aspects of climate related risks.

Linking all six of these frameworks together creates a network system useful in incorporating climate risk management into a financial-accounting approach. The importance of three of these frameworks in developing this network has recently been recognized in a 2017 joint publication by the SASB and the CDSB, *Converging on Climate Risk: CDSB, the SASB and the TCFD*. The publication tries to align the CDSB Framework and the SASB Metrics with TCFD principles.[26] If complete agreement can be reached among the three groups, a financial-accounting approach might be possible. A single financial-accounting approach would be desirable for moving towards a conventional financial-accounting standard.

Financial-accounting framework extended to federal agencies by statutes

A similar financial-accounting framework can be extended to include federal agencies by a network of existing statutes. The network of existing statutes consists of four groups of statutory authorities: (1) a statute requiring a federal agency to safeguard its assets, (2) a statute requiring a federal agency to manage high risk management challenges identified by either the agency's Inspector General's Office or the U.S. Government Accountability Office (GAO), (3) the statute requiring a federal agency to apply climate science research findings pursuant to its statutory duties under the federal agency's Authorization Act, and (4) the statute requiring a federal agency to apply climate science research findings pursuant to its statutory duties under a federal agency's duty to comply with federal laws. Linking these four statutory groups together forms a networked financial-accounting framework for climate-related risk management (Fig. 3.3).

The strongest statutory requirement to extend a financial-accounting framework to a federal agency is the statute that requires an agency to safeguard its assets (e.g., funds, property, and other assets) from loss, 31 U.S. Code (C.) §3512. [27] The requirements implementing this statute include: (1) internal control, (2) enterprise risk management, and (3) federal accounting standards. Internal control requires managers to define objectives clearly to enable the identification of risks and define risk tolerances. Internal control also requires managers to identify, analyze and responds to risks related to achieving the defined objectives.[28]

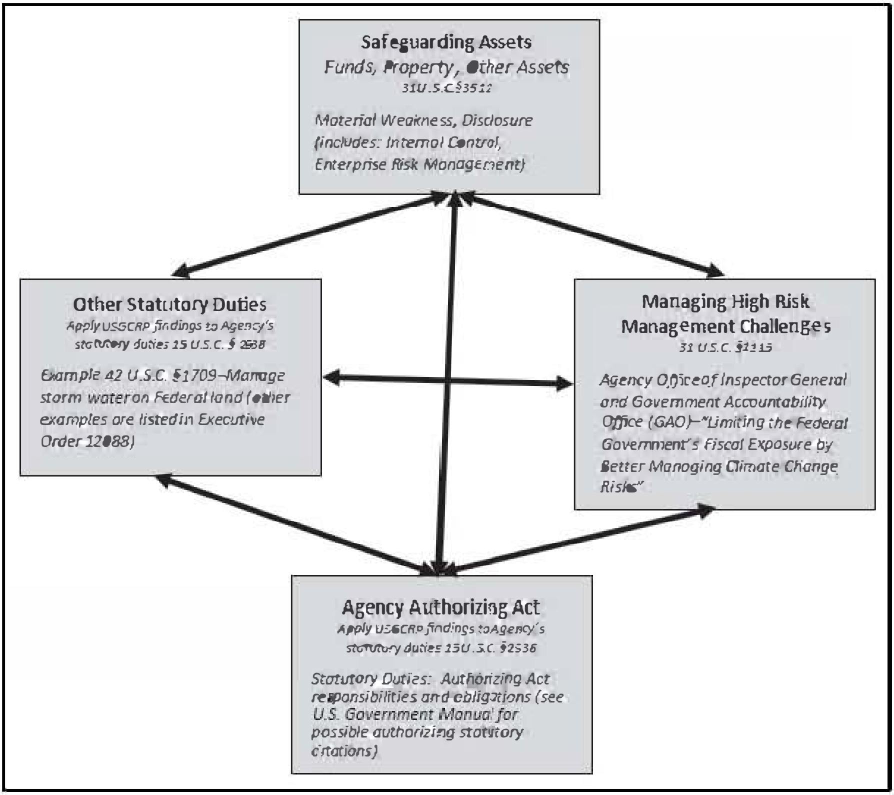

Fig. 3.3. Federal agency perspective: Climate risk management framework

In addition to internal control requirements, there are ERM requirements that can be applied to the management of an agency's climate-related risks. The elements of ERM include: (1) identify risks, (2) assess risks, (3) select risk response and (4) monitor risks.[29] Federal agency management of climate-related risks is specifically mentioned in a U.S. GAO publication.[30]

Further, there are federal accounting standards established by the Federal Accounting Standards Advisory Board that are triggered when an asset is lost due to a climate-related risk. As an example, when a long-life asset is lost, it may be reportable in the agency's annual financial statement as an "impairment".[31] Finally, if the loss is so great as to the cause a failure of an agency from achieving a statutory goal, it must be reported to the U.S. Congress as a "Material Weakness".[32] These are strong incentives to manage climate-related risks.

A second statutory requirement for a financial-accounting framework for a federal agency is that it must manage identified "high risk management challenges" (31 U.S.C. §1115). These challenges are identified by the agency's Office of Inspector General or the U.S. GAO. The GAO has already identified the federal government's fiscal exposure to climate risks as a high risk.[33] Past management challenges centered on information technology (IT) and other capital programming projects should serve as learning patterns as to how to handle climate-related risks.[34]

A third statutory requirement is that a federal agency must apply U.S. Global Change Research Program findings in compliance with its Statutory Authorization Act (15 U.S.C. §2938); that is the statute(s) that establish the agency's mission and goals. It can be difficult identifying all these statutes, but a good starting point to begin this legal research effort is *The U.S. Government Manual*.[35] This document is printed by the U.S. Government Publishing Office and is updated annually. Each federal entity has a descriptive narrative in the Manual, the narrative typically including the entity's statutory history.

A fourth statutory requirement is that a federal agency must apply U.S. Global Change Research Program findings in compliance with its "other non-Authorization Act" Statutory duties (15 U.S.C. §2938). The statutory duties are specifically those statutory responsibilities and obligations that apply to federal agencies. It can be extremely difficult to identify these statutes. One starting point for doing this legal research is to identify statutes that have a "waiver of federal sovereign immunity"; sovereign immunity is a legal doctrine by which a governmental entity cannot commit a legal wrong and is immune from civil and criminal liability. As an example, a good list of waivers of federal sovereign immunity is typically found in environmental statutes.[36]

These four statutory requirements form the basis for federal agencies to manage climate-related risks. In managing climate-related risks, federal agencies can look to best practices. Best practices as models would include those practices that have been identified in non-federal government sectors. This means that each individual federal agency can independently incorporate (adopt) best practices, approaches, such as those provided by: (1) academia, (2) non-profit organizations, (3) business-management organizations, and (4) other regulatory entities. More specifically, best practices could include approaches of: (1) Lash and Wellington, (2) SEC, (3) CDSB, (4) SASB, and (5) TCFD.

Conclusion

In closing, there are several viable frameworks, including those with a solid financial basis, to help protect assets and supply chains from the risks associated with climate change for businesses and government entities alike. For further information, see chapter ten, *Climate Risk Management: Implementation Aspects*.

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CHAPTER FOUR

ADJUSTING PRECIPITATION INTENSITY-DURATION-FREQUENCY (IDF) CURVES IN ENGINEERING DESIGN

MARK J. KLINGENSTEIN[1]

Abstract

This paper builds upon an article prepared by the author in 2016, which was subsequently published as a chapter in **Demystifying Climate Risk Volume II: Industry and Infrastructure Implications**.[1] That paper examined modeling and statistical tools for translating Global Circulation Model (GCM)-based projections into point-specific, intensity-duration-frequency (IDF) projections for short rainfall durations. The 2016 paper further discussed the importance of these projections in incorporating climate resilience when upgrading existing stormwater infrastructure and designing future stormwater infrastructure.

This paper examines why the adoption of climate-adjusted IDF curves may be appropriate for public agencies. The author investigates the degree to which these curves have been incorporated in the United States (U.S.) at the federal, state, and municipal levels. The study concludes that U.S. adoption of climate-adjusted IDF curves is limited, but that Canadian counterparts have apparently made more progress, perhaps because of the creation of an infrastructure vulnerability committee in that country.

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Introduction and background information

Current climate change science suggests that an increasing average global temperature may result in regionally localized impacts on precipitation patterns and amounts. Although projected changes in average precipitation across much of the U.S. appear moderate – in some cases an increase, in others a decrease, depending on region – increases in intense precipitation are generally projected across the country. The most significant increases are projected for the eastern portion of the continental U.S.[2]

In the author's 2016 paper, he described the various approaches to converting climate global and regional change projections to corresponding projections applicable at very small spatial scales and short temporal scales; this process is known as "downscaling". Downscaling involves a number of methodologies for translating GCM outputs to these much more granular spatial and temporal scales.

If these projections of future rainfall conditions prove correct, the resulting increases in intense precipitation will have a negative impact on the functionality of stormwater infrastructure. These impacts will be borne by both systems that are now in service, and those that are currently being designed or constructed.

The design of drainage infrastructure requires an understanding of intense precipitation at scales ranging from essentially a single point to what in climate science one considers regional. Furthermore, drainage infrastructure is designed to manage runoff associated with a particular storm recurrence frequency and duration – for example, to provide protection for the 5-year, 2-hour storm event. The specified storm event defines the "level of service" to be provided by the drainage system.[2]

Very short event durations are often important in the design of what are known as "minor" drainage system components.[3] This can pose challenges to the consideration of climate change in drainage design.

In the design of drainage system components, an important concept is a given catchment's Time of Concentration ("ToC"). The U.S. Geological Survey (USGS) defines ToC as:

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[2] Alternately, recurrence frequency may be expressed as a probability. For example, a 5-year event has a 20% probability of occurring in a given year. Expressing recurrence frequency in this alternate manner may more accurately convey the intent of the statistical characterization to the average layperson.

[3] "Minor" components are the smaller portions of the system that collect and initially convey runoff from small catchment areas. Although individually small, much like the smaller branches on a tree, they collectively make up a substantial fraction of the overall drainage system.

> "The time required for water to flow from the farthest point on the watershed to the (point of interest)."[4]

Furthemore,

> *"the timing of peak flow at a point is related to the time required for all the area that drains to that point to contribute to the flow at that point."*

ToCs provide important information for the calculation of the peak flows associated with a given rainfall event.

In small catchments and the upstream portions of large drainage systems, ToCs can be very small, often less than one hour, and in many cases, as little as 10 minutes or less. As a result, IDF information for durations of one hour or less can have a big impact on the sizing of many drainage infrastructure components.

Unfortunately, looking at the impact of climate change on short duration IDF relationships poses some specific challenges. As described in the author's prior paper,[1] these challenges are due largely to the relatively coarse granularity of GCMs and (Regional Circulation Models) RCMs. Furthermore, even the historic record has a relatively limited amount of long-term, sub-hour precipitation data

The characteristics of such events are location-specific, and as different "levels of protection" may be appropriate for different types of facilities, the characteristics of various storm return frequencies and durations have been identified based on "long-term" rainfall records. IDF curves are typically generated using either a maximum event series or a maximum partial duration series from stations with high quality, long-term (30 years or more) rainfall records. These data are analyzed using one of several statistical extreme value distribution methods to generate rainfall intensities for each selected return frequency.

The most widely used means of presenting rainfall return frequency information are IDF or Depth-Duration-Frequency (DDF) curves or tables. Individual IDF/DDF curves present combinations of two of the three IDF/DDF factors at a single specified value of the third factor. Inmost cases, combinations of intensity/duration or intensity/frequency are plotted. A series of curves is therefore used to provide intensity/duration data for a range of specified return frequencies at a given location. Fig. 4.1 from the National Weather Service's Precipitation Frequency Data System[5] illustrates IDF/DDF curve presentation.

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4 https://water.usgs.gov/wsc/glossary.html#T.

5 https://hdsc.nws.noaa.gov/hdsc/pfds/.

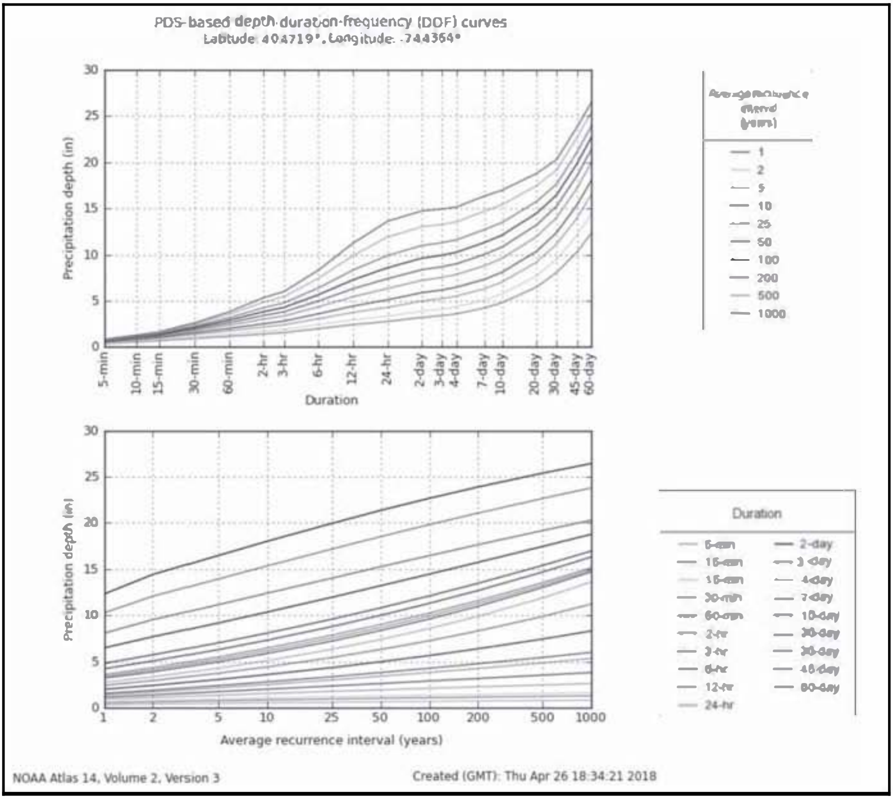

Fig. 4.1. Example IDF curves

Currently, most available IDF information assumes that the IDF/DDF relationships in the "long-term" rainfall record will continue to apply in the future an assumption of stationarity, or stationary long-term climate conditions. *If stationarity is not a valid assumption – particularly if intense rainfall events become more frequent – new infrastructure will not perform as expected, and the performance of existing drainage systems will degrade.*

Drainage systems across the U.S. represent an extremely large infrastructure investment. A significant fraction of that infrastructure will require repair, rehabilitation and/or replacement in the next several decades, as much is at the end of its service life.

In its 2012 Clean Watersheds Needs Survey,[3] the U.S. Environmental Protection Agency (EPA) estimated that the next 5 years of municipal stormwater infrastructure needs for addressing non-compliance with stormwater regulations was $19.2 billion, while that required by municipal combined sewer systems[6] for the same period was $48 billion dollars. These estimates do not include maintenance and repair needs not directly linked to regulatory compliance, and thus represent only a modest fraction of short-term municipal drainage infrastructure investment needs. They likewise do not include anticipated drainage investment needs for other significant public infrastructures such as those owned and operated by state Departments of Transportation (DOTs). Based on the author's experience with drainage infrastructure, *public drainage infrastructure investment needs in the U.S. over the next two decades will likely be at least several hundred billion dollars.*

Public entities' adoption of climate change-adjusted IDF curves

Many public agencies have developed or are developing climate change action plans. These plans typically include both mitigation and adaptation objectives and actions. As a follow-up to the author's 2016 paper, a logical question was "have public agencies actually incorporated the use of climate change-adjusted IDF curves/tables into their stormwater drainage design guidance?"

To begin to answer that question, a survey of websites for two types of agencies was undertaken: (1) the U.S. Department of Transportation (DOT) and the DOTs of all 50 U.S. states, and (2) a selection of the 100 largest municipalities in the U.S.

Federal and state DOTs were selected for investigation for several reasons. First, drainage design is a critical component of all roadway design, and as a result, DOTs all have very detailed drainage design requirements and guidelines. Also, roadway drainage represents one of the largest categories of stormwater drainage in the U.S. Total U.S roadway area is listed by the U.S. DOT as 8,736,587 mile-lanes, which assuming an average lane width of 11 feet, is approximately 17.4 million square miles of roadway surface. A portion of that roadway area lacks piped drainage – primarily rural roads – but nonetheless, roadway drainage represents a significant fraction of the U.S. drainage infrastructure.

Major municipalities were also selected for investigation for several reasons. Major municipalities are by their nature generally dense urban areas, with a high percentage of Directly Connected Impervious Area

[6] Combined Sewer Systems collect and manage both sewage and stormwater in one system of pipes.

(DCIA) and extensive drainage systems to manage the runoff from that DCIA. As such, the consequences of inadequate stormwater drainage capacity are likely, on average, to be more significant in dense urban areas than in less developed areas. Major municipalities were also judged of interest based on the author's experience that large municipalities are often "early adopters" of new technical developments and initiatives.

Investigation methodology relied upon Boolean searching of the agencies' web sites, with the following objectives:

- Generally, understand each agency's climate change stance and program(s); and
- Acquire each agency's drainage design manual/guidelines, to allow the determination of whether climate change adjusted IDF data use was required, encouraged, or allowed.

The following subsections examine the precipitation-related climate change adaptation efforts to date of these two categories of public agencies.

U.S. Department of Transportation/Federal Highway Administration

The U.S. DOT was established by Congressional action in 1966. Among its transportation-related missions is oversight of the design, construction, operation and maintenance of the Nations roadways and bridges. The organization within U.S. DOT tasked with that responsibility is the Federal Highway Administration (FHWA).

FWHA's overall policy regarding climate change preparedness and resilience is most recently set forth in FHWA Order 5520.[4] That order's requirements are based upon the following stated assumptions:

a. *"Climate change and extreme weather events present significant and growing risks to the safety, reliability, effectiveness, and sustainability of the Nation's transportation infrastructure and operations.*
b. *The impacts of a changing climate (such as higher temperatures, sea-level rise, and changes in seasonal precipitation and the intensity of rain events) and extreme weather events are affecting the lifecycle of transportation systems and are expected to intensify. For example, sea level rise coupled with storm surges can inundate coastal roads that would not have inundated in the past, necessitate more emergency evacuations, and require costly, and sometimes recurring, repairs to damaged infrastructure. Inland flooding from unusually heavy downpours can disrupt traffic, damage culverts, and reduce service life.*

High heat can degrade materials, resulting in shorter replacement cycles and higher maintenance costs.

c. *While transportation infrastructure is designed to handle a broad range of impacts based on historic climate, preparing for climate change and extreme weather events is critical to protecting the integrity of the transportation system and the sound investment of taxpayer dollars."*

The Order goes on to note that the resulting FHWA policy regarding climate change will be implemented by the following actions:

a. *"Identifying and removing administrative, regulatory, and policy barriers that discourage climate change and extreme weather event preparedness and resiliency or unintentionally increase the vulnerability of transportation systems to these risks.*
b. *Encouraging State departments of transportation (DOT), metropolitan planning organizations (MPO), Federal land management agencies (FLMAs), tribal governments, and others to develop, prioritize, implement and evaluate risk-based and cost-effective strategies to minimize climate and extreme weather risks and protect critical infrastructure using the best available science, technology and information.*
c. *Developing and providing technical assistance, research, and outreach, and encouraging the development and use of transportation-specific vulnerability assessment and adaptation tools.*
d. *Clarifying and informing State DOTs, MPOs, FLMAs, tribal governments, and others of existing funding eligibilities to support resiliency and adaptation in the delivery of title 23 programs.*
e. *Developing research and tools, providing technical assistance, and building partnerships with State DOTs and MPOs, particularly in development and analysis of adaptation, preparedness, and resiliency options.*
f. *Encouraging the consideration of climate change and extreme weather event risks, preparedness and resiliency in the delivery of programs, such as in the risk-based asset management plans State DOTs are required to develop under MAP-21.*
g. *Updating planning, engineering, and operations guidance to include consideration of climate change and extreme weather event resilience.*
h. *Reporting on progress through the US DOT Adaptation Plan and internal FHWA strategic planning activities."*

The FHWA's efforts to satisfy the above policy-mandated actions include its development of a climate change and extreme weather vulnerability assessment tool.[5] This tool was developed to establish an assessment process tailored to the needs of the transportation community, which focuses on both vulnerability as well as criticality, so as to allow assessment efforts to direct resources toward assets whose long-term performance is most likely to benefit from such evaluation efforts.

This assessment tool was developed and validated via two state/local agency partnered pilot programs in 2010-2011 (Pilot 1) and 2013-2015 (Pilot 2). In Pilot 1, a conceptual assessment methodology was applied, which resulted in the development of the 2012 *Climate Change and Extreme Weather Vulnerability Assessment Framework*. Pilot 2 then validated the 2012 *Climate Change and Extreme Weather Vulnerability Assessment Framework* with its application by additional agencies. These pilots were carried out by the state or local agencies with teclmical and funding support by FHWA; see Fig. 4.2.

Fig. 4.2. FHWA pilots 1 and 2 partner agencies

An adaptive management strategy, the *Framework* specifically identifies the intensification of extreme precipitation events as a key climate change for which asset vulnerability should be considered.

The FHWA has supported and encouraged the consideration of climate change impacts on transportation systems by its interpretation of the funding eligibility rules that apply to federal transportation funding programs. FHWA's September 24, 2012 memorandum, *Information: Eligibility of Activities to Adapt to Climate Change and Extreme Wet Weather Events*

Under the Federal-Aid and Federal Lands Highway Programs was issued to ensure consistent application of those interpretations by FHWA divisions and field offices. To quote from that memorandum:

> *"In general, activities to plan, design, and construct highways to adapt to current and future climate change and extreme weather events are eligible for reimbursement under the Federal-aid program and for funding under the Federal Lands program."*

In summary, the FHWA has recognized the potential impact of climate change on transportation systems, including on the drainage systems serving those systems; supported the development of protocols and tools to assist agencies in considering those impacts; and, perhaps most importantly, facilitated such activities by considering them eligible for federal funding. FHWA does not appear to have yet issued any guidance specifically calling for the use of climate change adjusted IDF curves in highway/roadway drainage design.

While the FHWA has not determined that mandating the use of climate change adjusted IDF data is currently justified, USDOT and the FHWA have indirectly encouraged the investigation of its applicability by individual agencies. This encouragement has included the U.S. DOT's development of a spreadsheet-based tool, the *U.S. DOT CMIP Climate Data Processing Tool,*[7] to assist local and state technical personnel in accessing and using downscaled climate projections in vulnerability assessments and to support project design. The tool utilizes data from the U.S. Bureau of Reclamation's Downscaled CMIP3 and CMIP5 Climate and Hydrology Projections (DCHP) website.[8] The *US DOT CMIP Climate Data Processing Tool User's Manual*[9] notes:

> *"The purpose of the* (Tool) *is to process readily available downscaled climate data at the local level into relevant statistics for transportation planners."*

For additional information regarding the FHWA's past and ongoing climate change-related activities, see:
https://www.fhwa.dot.gov/environment/sustainability/index.cfm.

[7] https://toolkit.climate.gov/tool/cmip-climate-data-processing-tool.
[8] http://gdo-dcp.ucllnl.org/downscaled_cmip_projections.
[9] Downloadable with the Tool.

U.S. State Departments of Transportation (DOTs)

U.S. state DOTs are responsible for the oversight of roadways within their respective jurisdictions, including the design of roadway drainage. In light of this, highway/roadway hydraulic design manuals (or consolidated roadway design manuals, for states where a separate hydraulic design manual was not identified) were obtained from each state DOT website and reviewed to determine if (1) the use of climate-adjusted IDF curves was specified, or (2) if the consideration of climate change impacts in roadway drainage design was encouraged or discussed. As these manuals together are quite voluminous, each document's table of content was reviewed, and each PDF file was searched for the words "climate" and "rainfall" to identify any relevant sections. Each DOT's website was also reviewed, to identify separate bulletins updating the hydraulic/drainage design manual regarding climate change.

This review did not reveal any state DOTs that are currently requiring the use of climate-change-adjusted IDF/DDF curves or tables. A limited number of state DOT drainage/hydraulic design manuals do discuss change and its possible impacts on roadway drainage systems.

States whose hydraulic design manuals were found to address climate change, and the way climate change was addressed, were as follows:

Vermont

Section 1.5.2 of Vermont's DOT (VTrans) May 28, 2015 "Hydraulics Manual"[6] states:

> *"Regulations and current standard practice typically rely on the statistical patterns in past hydrologic data to estimate peak flows for hydraulic design. However, these methods often do not account for trends in increasing peak flows that are widely attributed to changing climate patterns. The designer should be aware of the limitations in assuming stationarity for design storm estimates and evaluate whether or not that assumption is appropriate on a case-by-case basis. Consult with the VTrans Hydraulics Engineer before factoring climate change into a hydrologic analysis."*

North Carolina

Section 3.6, *Project Commitment Regarding Climate Change and Extreme Weather Events* of North Carolina DOT's *Guidelines for Drainage Studies and Hydraulic Design*[7] states:

"NCDOT will follow FHWA's policy as set forth in FHWA Order 5520, "Transportation System Preparedness and Resilience to Climate Change and Extreme Weather Events" and guidance as set forth in FHWA's publications "Highways in the River Environment-Floodplains, Extreme Events, Risk, and Resilience" June 2016, (FHWA-HIF-16-018) and "Highways in Coastal Environment: Assessing Extreme Events" October 2014, (FHWA-NHI-14-006) to minimize climate and extreme weather risks and protect transportation infrastructure."

Illinois

Illinois DOT's July 2011 Drainage Manual does not address climate change. However, the Manual specifies that hydrologic analyses be carried out using rainfall IDF data from the Illinois State Water Survey's Frequency Distributions and Hydroclimatic Characteristics of Heavy Rainstorms in Illinois (Bulletin 70). Interestingly, Bulletin 70 specifically discusses the issue of non-stationarity in rainfall records throughout the state as being one of the reasons for the re-evaluation of rainfall IDF relationships in 1989.

*"Some specific needs led to the undertaking of this study. First, Illinois frequency relations had not been updated since 1959-1961 (Huff and Neill, 1959; Hershfield, 1961). **Second, further stimulation for the study resulted from recent findings (Huff and Changnon, 1987) that an apparent climatic trend operated on the frequency distributions of heavy rainstorms in Illinois from 1901-1980.**"*

The Illinois State Water Survey expanded upon Huff et al.'s prior work, and found that most stations in Illinois display an increase in the amount of rainfall associated with a specific frequency. Bulletin 70 concluded that based on this observed trend, regular updating of the IDF relationships used for hydraulic design in the state was appropriate.

California

Chapter 810 of CalTrans' *Highway Design Manual*, (6th Edition, 2016)[10] discusses non-stationarity as follows:

"In Index 818.1, the assumption behind flood probability and frequency analysis is that climate is stationary. Stationarity assumes that hydrology varies within an unchanging envelope of natural variability, so that the past accurately represents the future. It has been a basic assumption used for

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[10] http://dot.ca.gov/design/manuals/hdm.html.

many years in the planning and design of bridges and culverts and continues to represent the current state of practice that serves the engineering community well.

Climate change as well as better understanding of climate variability have presented a challenge to the validity of this assumption.

Today, there is growing recognition that, despite its successful application in the past, the assumption of stationarity may not accurately represent the future. However, until a multi-disciplinary consensus is reached on future trends that can be expected, stationarity will continue to be utilized with current procedures.

To minimize uncertainty, designers should continue to utilize existing hydrologic tools with the most current datasets available for rainfall and runoff. Observed trends can then be quantified and placed in the context of the uncertainty associated with the frequency estimates themselves.

(1) Nonstationarity and Climate Variability.

Changes in land use, changing groundwater levels, and urbanization are examples of nonstationarity within a watershed that can affect hydrologic response. The Intergovernmental Panel on Climate Change (IPCC) has stated that "Climate change challenges the traditional assumption that past hydrological experience provides a good guide to future conditions". Although the assumption of stationarity is being challenged, there is no consensus within the scientific or engineering community on a viable replacement."

In short, a number of state DOTs are investing energy and resources into the issue of climate change and its impact on transportation infrastructure. However, none have determined that the use of climate adjusted IDF information is appropriate.

Selected major U.S. cities

A significant number of large U.S. cities have ongoing/developing climate change action plans. Many of these plans focus on mitigation measures. Many also include the evaluation of adaptation measures to address identified climate change related threats. The author investigated the following "top 10" cities (based upon population) to determine the degree to which any had adopted, or appeared to be considering, the adoption of climate change-adjusted IDF curves for their drainage manuals (Table 4.1).

Table 4.1. U.S. cities investigating IDFs and their population rankings

City	Population ranking	City	Population ranking
New York City, NY	1	Indianapolis, IN	13
Chicago, Il	3	San Francisco, CA	14
Houston, TX	4	Boston, MA	21
Philadelphia, PA	5	Seattle, WA	22
Dallas, TX	9	Portland, OR	28
Jacksonville, FL	12		

Source of population rankings: www.citymayors.com

New York City, NY

New York City's complex, multi-faceted climate change program is over 10 years old. In 2003 the NYC Department of Environmental Protection (NYCDEP) established a Climate Change Task Force to identify and characterize climate change risks and to formulate appropriate response measures. This Task Force included technical staff from various city departments, the Mayor's Offices of Environmental Coordination, and Long-Term Planning and Sustainability, as well as technical experts from academia (Columbia University), and technical consultants (Hydroqual).

A core component of NYC's program was, like Boston's, the establishment of a panel – The New York City Panel on Climate Change (NPCC) – charged with the development of climate change impact projections. In fact, there have been three panels convened by NYC – NPCC, NPCC2 and NPCC3 – each tasked with advancing the city's understanding of the climate risks it faces in the coming century.

In its *Climate Risk Information 2013; Observations, Climate Change Projections and Maps* (NPCC2, June 2013)[11], the NPCC2 provided predictions for the average number of days per year with rainfall at or above 1, 2, and 4 inches, in the 2020s and in the 2050s (Table 4.2).

[11] www1.nyc.gov/site/orr/projects/publications.page.

Table 4.2. Average number of days per year for rainfall ≥ 1, 2, and 4 inches for 2020s and 2050s

Extreme event	Baseline (1971–2000)	Low estimate (10th %)	Middle range (25th %-75th %)	High estimate (90th %)
Days/year with rainfall ≥ 1 inch **2020s**	13	13	14–15	16
Days/year with rainfall ≥ 2 inch **2020s**	3	3	3–4	5
Days/year with rainfall ≥ 4 inch **2020s**	0.3	0.2	0.3–0.4	0.5
Days/year with rainfall ≥ 1 inch **2050s**	13	13	14–16	17
Days/year with rainfall ≥ 2 inch **2050s**	3	3	4–4	5
Days/year with rainfall ≥ 4 inch **2050s**	0.3	0.3	0.3–0.4	0.5

These predictions were generated by the NPCC2 using the outputs from 35 GCMs and 2 Representative Concentration Pathways (RCPs) – 4.5 and 8.5 – to produce outputs for temperature and precipitation. To evaluate precipitation (and temperature) extremes, a somewhat simplified hybrid approach was used, in which monthly changes generated by each GCM were used to generate scaling factors that were applied to the 1971 to 2000 baseline Central Park daily data record.

While useful in suggesting the possible magnitude of the change that might be expected in extreme precipitation events, they do not provide a specific basis for changing drainage design.

In fact, NYC's sewer design standard – the 3-year event prior to 1970; the 5-year event since then – was in 2013 applied using IDF curves generated from the 1903 to 1951 rainfall record! In 2013, NYCDEP released its *NYC Wastewater Resiliency Plan; Climate Risk Assessment and*

Adaptation Study (NYCDEP, October 2013).[12] As part of that effort, NYCDEP carried out an analysis of recent rainfall records (1969-2010) to see if IDF curves based on the more recent data varied significantly from those in use based on the rainfall record from the first half of the 20th century. The results of the analysis are illustrated in Fig. 4.3.

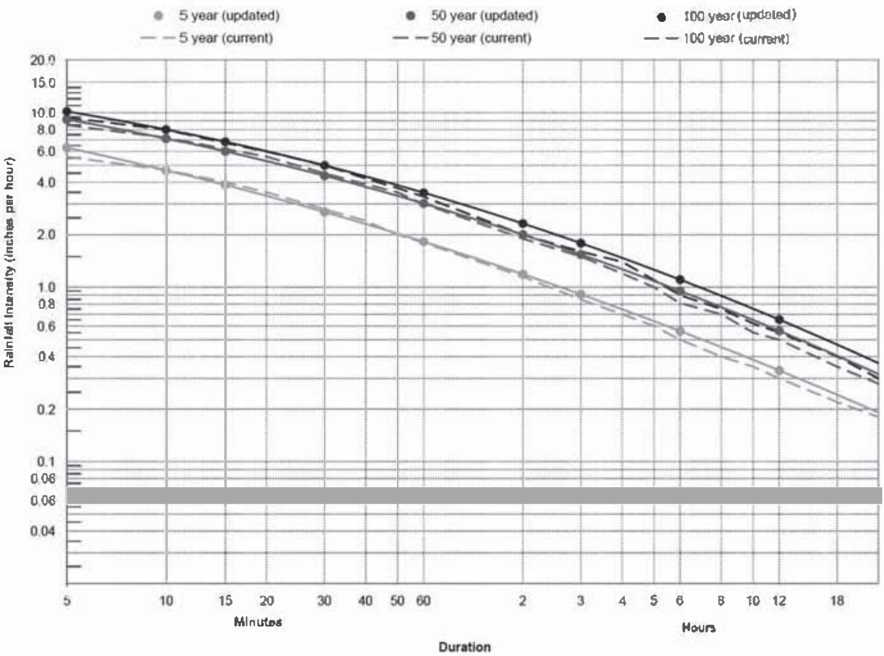


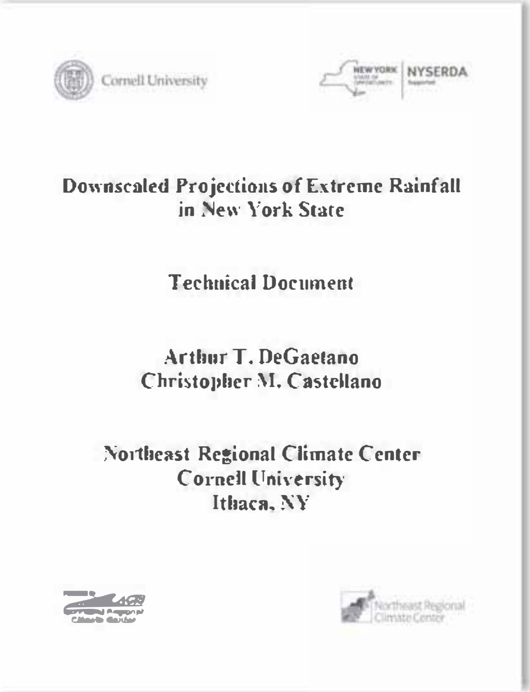
Fig. 4.3. NYC comparison of updated and baseline IDF curves

NYCDEP noted that in most of the City's sewersheds time of concentration can be up to 100 minutes, and since the original and updated 5-year IDF curves are very similar at durations up to 2 hours, that continued use of the existing curve to design drainage appeared to remain appropriate. Note that the intensity at 5 minutes actually is approximately a half inch per hour higher in the updated curve than in the original 5-year curve.

In April 2017, the Mayor's Office of Recovery and Resiliency released a document that reverses the position noted above regarding the continued

12 http://www.nyc.gov/html/dep/html/about_dep/wastewater_resiliency_plan.shtml.

applicability of NYC's existing IDF curves. That document is the *Preliminary Climate Resiliency Design Guidelines, Version 1.0* (NYC, 4/21/17).[13]



Cornell University

NEW YORK STATE OF OPPORTUNITY | NYSERDA

Downscaled Projections of Extreme Rainfall in New York State

Technical Document

Arthur T. DeGaetano
Christopher M. Castellano

Northeast Regional Climate Center
Cornell University
Ithaca, NY

Northeast Regional Climate Center

Fig. 4.4. NYC Mayor's Office of Recovery and Resiliency document reversing the use of existing IDF curves

This document (the *Preliminary Guidelines*) provides design criteria adjustments to address increasing high temperatures, increased intense precipitation and sea level rise. For increasing intense precipitation, the *Preliminary Guidelines* provide adjusted IDF curves for 5-year, 50-year, and 100-year events, based upon the NPCC impact prediction modeling analyses described above.

The adjusted IDF curves as presented in Appendix 2 of the *Preliminary Guidelines* are presented in Fig. 4.5, 4.6, and 4.7.

[13] http://www1.nyc.gov/site/orr/index.page.

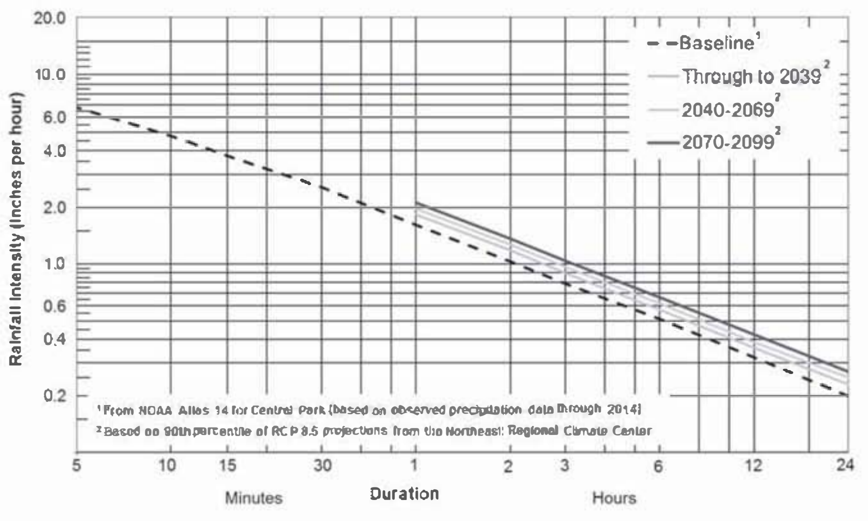


Fig. 4.5. Projected and baseline IDF curves for the 5-year storm event in Central Park, NYC

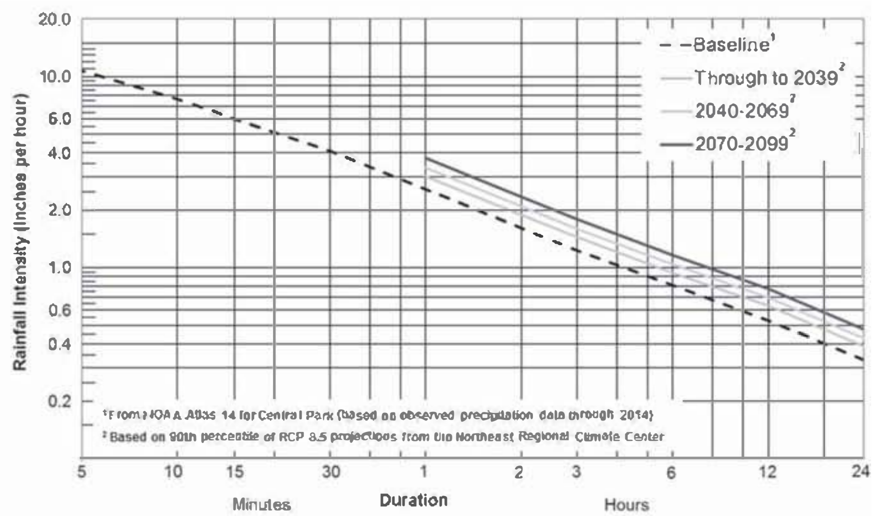


Fig. 4.6. Projected and baseline IDF curves for the 50-year storm event in Central Park, NYC

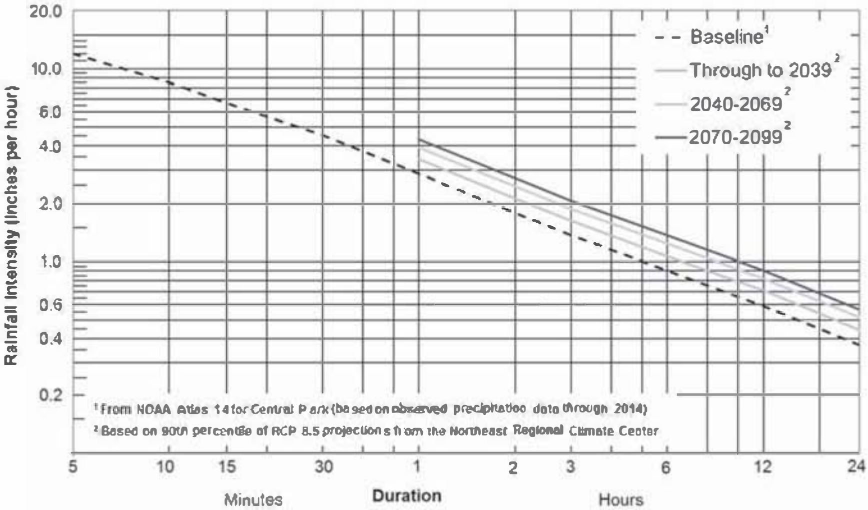


Fig. 4.7. Projected and baseline IDF curves for the 100-year storm event in Central Park, NYC

The reader will note that adjusted curves are not provided for durations less than 60 minutes. The *Preliminary Guideline* document notes:

> *"Another resource to be developed includes projected sub-hourly rainfall intensities, which will be a primary tool in drainage planning. While considerable uncertainty exists regarding projections at this timescale, the City is seeking guidance from its academic partners to determine reasonable estimates of sub-hourly future rainfall intensity."*

The *Preliminary Guidelines* document indicates that these preliminary adjusted design criteria would be refined through the remainder of calendar year 2017, with final criteria being released by the end of the year. The *Preliminary Guidelines* also clearly indicates that it is NYC's intention to continue to refine these guidelines as climate science advances.

NYC is reportedly implementing a number of pilot projects that will conform to the Preliminary Guidelines to inform the finalization process.

The results of the reviews of the U.S. municipalities were as follows:

- Only one US city New York City, NY was found to have developed or be developing climate change-adjusted IDF curves for the design of storm drainage systems (they are still in development); and

- The other cities reviewed range from having no formal climate change program to very developed, detailed programs with literally hundreds of identified actions and initiatives. These programs display a range of foci between mitigation and adaptation.

Addendum: Canada

Finally, as part of a more general internet search regarding IDF adjustment efforts, the author identified several Canadian cities, including Welland, Ontario, that have developed climate-adjusted IDF information.

Canada's Public Infrastructure Vulnerability Committee (PIEVC) was established to conduct an engineering assessment of the vulnerability of Canada's public infrastructure to climate change impacts. The PIEVC has developed a protocol for the conduct of climate change vulnerability assessments, including those impacts related to changes in precipitation patterns. The PIEVC protocol was used to carry out the City of Welland's assessment.

Welland, Ontario, Canada

Welland, Canada is located in southeastern Ontario, approximately 10 miles southwest of the Niagara Falls, immediately west of Niagara Falls, Ontario. Welland's population is approximately 52,000. Welland's drainage infrastructure is comprised of a Combined Sewer System in certain areas, and separate storm sewers in the remaining portions of the City. Welland's stormwater management design standard for "minor" drainage components is a 2-year storm.

Prior to 2000, Welland's IDF curves were from 1963, based on data from Buffalo, NY, from the 1930s through the 1950s. In 2000, Welland's IDF curves were updated based on the closest long-term record – Port Colborne, Ontario, located approximately 8 miles south of Welland on the shore of Lake Erie.

In the 2010 timeframe, a number of factors combined to cause Welland to decide to evaluate the possible impact of climate change on its drainage design standards. As part of its Combined Sewer Overflow (CSO) control efforts, Welland was in the process of separating portions of its combined sewer system. As such, it was designing and constructing a significant amount of new storm sewers. In addition, Welland had a history of localized surface flooding and basement backup[14] issues. The City wanted to ensure that new infrastructure would perform as designed for its service life.

In undertaking this assessment; Welland interestingly decided to look at projected futures centered on years 2020 and 2050. Such relatively near-term timeframes appear to be unusual in assessments such as this, given the typically long service lives of storm sewers and associated appurtenances such as pump stations.

Welland's assessment (Fig. 4.8) utilized downscaled climate projection data (temperature and precipitation) from the World Climate Research Programme's Coupled Model Intercomparison Project Phase 3 (CMIP3) multi-model dataset. Data from 16 GCMs and three emissions scenarios (from the 2000 Special Report on Emissions Scenarios) – SRES B1, A1B and A2 ("low", "medium" and "high," respectively) were included.

NATIONAL ENGINEERING VULNERABILITY ASSESSMENT
OF PUBLIC INFRASTRUCTURE TO CLIMATE CHANGE

CITY OF WELLAND
STORMWATER AND WASTEWATER INFRASTRUCTURE

Final Report

Development of
Projected Intensity-Duration-Frequency Curves
for Welland, Ontario, Canada

Prepared by
AMEC Environment & Infrastructure

February 2012

Fig. 4.8. Welland, Ontario, Canada's assessment utilizing data from the World Climate Research Programme

[14] "Basement backups" occur when sanitary, combined or storm sewers surcharge to the extent that the sewers contents backflow through floor drains and other fixtures into a building's lowest level – typically the basement.

Downscaling was carried out using a multi-step "delta" process. Welland first used the "delta" method to produce an adjusted baseline[15] data set for each model/emissions scenario combination. Deltas were calculated from the comparison of the simulated future period (2000-2099) to that of each simulation's "overlap" period (1950-1999).

Projected IDF relationships were then generated using a second "delta" process that utilized duration-specific generalized linear models, applied to the baseline data set and the adjusted Port Colborne data set for each duration, to generate DF information for that duration. Duration-specific deltas were calculated based on the two sets of DF information, and those DF deltas used to adjust the historical IDF data set.

The results from all models and all three emission scenarios were then pooled, and the statistics of the resulting set provided. A report providing the results of this assessment was released in February 2012. [8]

The author investigated, but was unable to identify, clear documentation of the adoption of the aforementioned assessment results by Welland. However, review of Welland's current drainage design standards[16] reveals evidence that Welland has adjusted the IDF curves that engineers are required to employ when designing drainage within the city.

As the city's design standards were updated in early 2013, the updated version could reflect the results of the assessment. The author sought the prior version of those standards to allow a comparison of the required IDF curves, however, he was unable to locate that earlier version of the standards. The author then utilized information provided in the assessment report to generate prior IDF values for the 2-year event to compare to those in the 2013 Design Standards. The results of that comparison are presented in Table 4.3.

[15] Welland employed a high-quality long-term precipitation data set from nearby Port Colbane as its baseline data set.

[16] City of Welland Design Standards (Welland, CA, February 2013).

Table 4.3. Comparison of Welland, Ontario, Canada IDF rainfall depth values (mm) for the 2-year storm

Duration, Hours	1963 Values	2000 Values	2013 Design Standard Values	90% 2020 Projected Values
1	23.4	22.9	27.0	27.2
2	27.3	27.6	32.8	33.2
6	31.9	34.8	42.8	42.6
12	-	42.0	50.0	46.8
24	-	48.0	58.1	57.6

mm = millimeters

This table, generated by the author, compares Welland's 2013 Design Standard Values for the 2-year storm with those generated from the 1963 IDF values, the 2000 IDF values and those from the 2020 90% prediction IDF values. This table suggests that Welland in 2013 revised its required design IDF values to reflect the 2020 90% predictions; however, the minor differences between the 2013 standard values and those from the February 2012 update report leave some uncertainty as how and to what degree Welland had incorporated its IDF evaluation into those 2013 Design Standards.

Also, use of 2020 predictions in standards released in 2013 would appear questionable for the design of stormwater infrastructure, given its long service life. Revising Welland's standards to reflect 2050 projections would better reflect the likely long life of future stormwater infrastructure.

Conclusions

Planning and building for the future is central to any community, big or small, in pursuing climate adaptation and resilience to reduce risk. While limited in scope, this study reveals some important trends in the current application of climate-adjusted precipitation IDF curves in engineering design. Specifically:

- In the U.S., the actual adoption of climate change-adjusted IDF curves into mandatory design standards does not appear to have been undertaken, or been considered, by many public entities.
- This limited consideration by public entities of modifying the IDF curves included in mandatory design standards appears largely due

to the widely recognized uncertainties currently associated with localized, short-duration rainfall predictions.

- Such consideration of the adoption of climate change adjusted IDF curves appears somewhat further along in Canada, largely due to the creation of Canada's PIEVC.
- As climate change modeling and downscaling techniques continue to evolve, it appears likely that continued increases in model granularities, as well as the inclusion of additional smaller scale precipitation mechanisms, may reduce the uncertainties currently associated with localized, short-duration rainfall predictions. This will likely encourage additional entities to undertake the type of assessments discussed in this paper.

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CHAPTER FIVE

POLLUTION PREVENTION OPTIONS ANALYSIS SYSTEM

JASON P. MARSHALL, SC.D.[1]

Background on alternatives assessment

An alternatives assessment looks comprehensively at the uses of chemicals of concern and the availability of safer, technically feasible, and affordable alternatives. These alternatives may be chemical substitutions, but are not limited to chemicals alone. The assessment can focus on modifications to a process or redesigning a product to facilitate the shift to safer options.

A challenge to any alternatives assessment is the availability of full and objective information. Technical performance and cost data may be available for well-established technologies, but much less so for emerging ones. Similarly, the lack of environmental, health, and safety (EHS) information for newer chemicals reduces confidence in assessment results.

Alternatives assessment rests on a three-legged stool: the technical, financial, and safety (including environmental, occupational, and general) aspects of each alternative.

In considering available EHS information, there are literally dozens of endpoints that could be selected (e.g., carcinogenicity, mutagenicity, flash

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[1] Jason Marshall directs the Toxics Use Reduction Institute Cleaning Laboratory. The lab works with companies, communities, and citizens to evaluate the performance of cleaning chemistries and equipment. Some of Dr. Marshall's recent projects include: promoting the adoption of alternatives to trichloroethylene for businesses in Massachusetts and Rhode Island; promoting safer ingredients in cleaning products resulting in recognition from U.S. EPA's Safer Detergent Stewardship Initiative at the Champion Level; participating in the Toxics Reduction Task Force Massachusetts Executive Order No. 515 that establishes an Environmental Purchasing Policy to examine specific areas of environmental procurement; and providing targeted technical assistance and guidance to agencies.

point), and conflicting reasons to choose many of them, or just a few. Choosing a few criteria simplifies the analysis, but leaves the distinct possibility that a crucial category may be neglected. On the other hand, using a large set of criteria increases the analysis effort concomitantly, and introduces the new problem of aggregating and comparing the information across all categories.

In 2012, a large group of environmental health scientists, advocates, funders, and policy makers met to create a set of principles for chemicals alternatives assessment. In 2013, the group worked to refine a consensus set of principles. These principles were based on earlier foundational work by: (1) the Lowell Center for Sustainable Production, (2) the Massachusetts Toxics Use Reduction Institute (TURI), (3) the Environmental Defense Fund, and (4) the BizNGO Working Group. These principles for alternatives assessment, shown in Table 5.1, are designed to guide a process for well-informed decision making that supports successful phase out of hazardous products, phase in of safer substitutes, and elimination of hazardous chemicals where possible.[1]

Included in the first principle is the reduction of chemicals that contribute to global warming such as greenhouse gases (GHGs). Global warming potentials (GWPs) were developed to allow for comparisons of different chemicals relative to the emissions of one ton of carbon dioxide (CO_2=1 GWP), as fossil fuel burning is a major contributor to global warming. The larger the GWP, the more that a given chemical warms the Earth compared to CO_2 over the same period (usually 100 years). While methane (CH_4) absorbs much more energy than CO_2, it persists in the atmosphere for a far shorter period, about 10 years, as compared to CO_2 emissions which can cause increases in atmospheric concentrations lasting thousands of years. Moreover, CH_4 is a precursor to ozone (O_3), itself a GHG.

Chlorofluorocarbons (CFCs), hydrofluorocarbons (HFCs), hydrochlorofluorocarbons (HCFCs), and perfluorocarbons (PFCs) are all chemicals of concern in this regard. Known as high-GWP compounds, they trap substantially more heat than CO_2 for a given amount of mass. The GWPs for these gases can be in the thousands or tens of thousands. Industrial applications for some high-GWP chemicals include: refrigeration and air conditioning, solvent cleaning, the manufacture and use of foam products, aerosol propellants, fire extinguishing, and sterilization. Perhaps surprisingly, the history of chemicals such as HFCs and PFCs involve their use as substitutes for ozone depleting substances (ODSs).[2] ODSs were phased out under the Montreal Protocol, a global agreement finalized in 1989, and the United States (U.S.) Clean Air Act Amendments of 1990.[3]

Table 5.1. Alternatives assessment process[4]

Principle	Definition
Reduce hazard	Reduce hazard by replacing a chemical of concern with a less hazardous alternative. This approach provides an effective means to reduce risk associated with a product or process if the potential for exposure remains the same or lower. Consider reformulation to avoid use of the chemical of concern altogether.
Minimize exposure	Assess use patterns and exposure pathways to limit exposure to alternatives that may also present risks.
Use best available information	Obtain access to and use information that assists in distinguishing between possible choices. Before selecting preferred options, characterize the product and process sufficiently to avoid choosing alternatives that may result in unintended adverse consequences.
Require disclosure and transparency	Require disclosure across the supply chain regarding key chemical and technical information. Engage stakeholders throughout the assessment process to promote transparency in regard to alternatives assessment methodologies employed, data used to characterize alternatives, assumptions made and decision-making rules applied.
Resolve trade-offs	Use information about the product's life cycle to better understand potential benefits, impacts, and mitigation options associated with different alternatives. When substitution options do not provide a clearly preferable solution, consider organizational goals and values to determine appropriate weighting of decision criteria and identify acceptable trade-offs.
Take action	Act to eliminate or substitute potentially hazardous chemicals. Choose safer alternatives that are commercially available, technically and economically feasible, and satisfy the performance requirements of the process/product. Collaborate with supply chain partners to drive innovation in the development and adoption of safer substitutes. Review new information to ensure that the option selected remains a safer choice.

Alternatives assessment shows great value as a methodology, but its utility would be improved by using a consistent set of assessment criteria from one assessor to another. This process provides the framework for *what* to do in an alternatives assessment, but begs the question about *how* to specifically conduct such a chemical review.

To assist those in the pursuit of a sound methodology that is repeatable, TURI looked to re-deploy its tool from 1995. This tool, known as the Pollutions Prevention Options Analysis System, focuses on a systematic way for users to compare toxics use reduction (TUR) changes at their facilities.

History of Pollution Prevention Options Analysis System (P2OASys)

In the mid-1990s, TURI developed a tool to help companies systematically determine whether the TUR options being considered may have unforeseen negative environmental, worker, or public health impacts. The original P2OASys provided the end user with a numerical hazard score for the inputted current chemical/process as well as the identified options. The resulting information allowed the user to combine the entered data with other information sources (cost and performance) and professional expertise to make decisions on TUR option implementation. By providing the user with a predetermined set of EHS criteria, the tool offered a consistent and repeatable examination of the potential impacts of TUR options, examining the total impacts of process changes, rather than simply those of chemical changes.

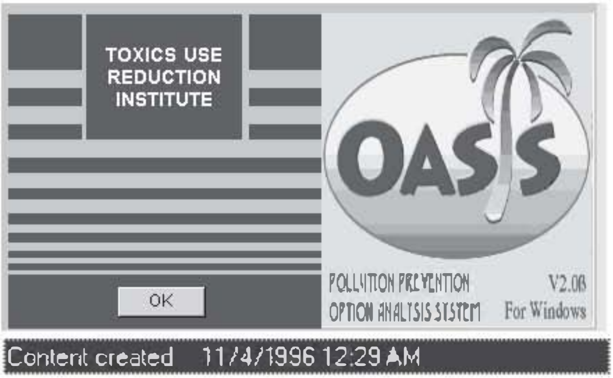

Fig. 5.1. Original P2OASys

The original system had 11 categories and utilized 61 endpoints. Categories and subcategories are listed in Table 5.2.

Table 5.2. P2OASys categories and subcategories

Category	Key criteria	Units
1. Acute human health	Inhalation LC50	parts per million (ppm)
	PEL/TLV	ppm
	PEL/TLV (dusts/particles)	mg/m^3
	IDLH	ppm
	Respiratory irritation	low/medium/high (L/M/H)
	Oral LD50	milligram/kilogram (mg/kg)
	Dermal irritation	L/M/H
	Skin absorption	L/M/H
	Dermal LD50	mg/kg
	Ocular irritation	L/M/H
2. Chronic human effects	Oral reference dose (RfD)	mg/kg/day
	Carcinogen	IARC/U.S. EPA class
	Mutagen	L/M/H
	Reproductive effects	L/M/H
	Neurotoxicity	L/M/H
	Developmental effects	L/M/H
	Respiratory sensitivity/disease	L/M/H
	Other chronic organ effects	L/M/H
3. Physical hazards	Heat	WBGT, °C
	Noise generation	A-weighted decibels (dBA)
	Vibration	m/S^2
	Ergonomic hazard	L/M/H
	Psychosocial hazard	L/M/H
4. Aquatic hazards	HWQC	milligrams per liter (mg/l)
	Aquatic LC50	mg/l
	Fish NOAEC	mg/l
	Plant EC 50	mg/l
	Observed ecological effects	L/M/H

Table 5.2. P2OASys categories and subcategories (cont.)

Category	Key criteria	Units
5. Persistence/ bioaccumulation	Persistence	L/M/H
	BOD half-life	days
	Hydrolysis half-life	days
	Bioconcentration	log kow
	BCF	kg/l
6. Atmospheric hazards	GHG	Y/N
	ODS	ODP units
	Acid rain formation	Y/N
	NESHAP	Y/N
7. Disposal hazards	Landfill	L/M/H
	EPCRA reportable quantity	pounds (lbs)
	Incineration	L/M/H
	Recycling	L/M/H
8. Chemical hazards	Vapor pressure	mm Hg
	Solubility in water	mg/l
	Specific gravity	N/A
	Flammability	0,1,2,3,4
	Flash point	°C
	Reactivity	0,1,2,3,4
	pH	pH units
	Corrosivity	L/M/H
	High pressure system	L/M/H
	High temperature system	L/M/H
	Mixture/reaction potential	L/M/H
	Odor threshold	L/M/H
	volatile organic compound (VOC)	L/M/H
9. Energy and resource use (includes carbon-based fossil fuels)	Non-renewable resources	L/M/H
	Water use	L/M/H
	Energy use	L/M/H
10. Product hazards	Upstream effects	L/M/H
	Consumer hazard	L/M/H
	Disposal hazard	L/M/H
11. Exposure potential	Exposure potential	L/M/H

Legend to Table 5.2 of terms not previously defined (in order of appearance):

LC50	lethal concentration for 50% of an exposed population	NOAEC	no observed adverse effect concentration
PEL	permissible exposure limit	EC50	half maximal effective concentration
TLV	threshold limit value	BOD	biological oxygen demand
mg/m^3	milligrams per cubic meter	log kow	a relative indicator of the tendency of an organic compound to adsorb to soil and living organism
IDHL	immediately dangerous to health or life (U.S. NIOSH)	BCF	bio-concentration factor
LD50*	lethal dose 50%	kg/l	kilograms per liter
IARC/ EPA	International Agency for Research on Cancer/ Environmental Protection Agency	ODP	ozone depletion potential
WBGT	Wet bulb globe temperature (for heat disorders)	NESHAP	National Emission Standards for Hazardous Air Pollutants
m/S^2	meters per second per second	U.S. EPCRA	Emergency Planning and Community Right-To-Know Act
HWQC	hardness-based water quality criteria	mm Hg	millimeters of mercury

Utilizing the tool required downloading from the host site and using Microsoft Excel to run it. The download was an improvement over the original method of requesting a 3.5" disk to be unzipped and installed. Under these conditions, the tool did not get a lot of use outside the Massachusetts Toxics Use Reduction Act (TURA) program and limited use within TURI, that is, by the laboratory.

Evolution of P2OASys, 2013-2016

The TURI Lab use of the tool for comparing solvent substitution in cleaning applications proved to be helpful for various projects.[5] The consistent endpoints from one chemical to the next allowed for simple explanations to client companies. The tool still required internal users to enter data and provide summaries of comparison, as the tool was cumbersome. In addition, internal discussions about the tool brought up the need to reaffirm data endpoints and categories.

As part of a funded research project through the Society for Chemical Hazard Communication, TURI hired a University of Massachusetts Lowell graduate student to conduct a review of the existing endpoints and compare them to the Global Harmonized System (GHS). The main outcome was the replacement of the endpoints in P2OASys that used basic categorization of L (low), M (medium), H (high). Key words from the GHS were added to P2OASys. When comparing quantitative endpoints, those that would have been considered worst case scenario were adopted. In addition, all units listed within GHS standards were considered for inclusion into the updated tool.

Upon review of the data collection and comparison process, in many cases P2OASys endpoints provided more restrictive values than GHS standards. Changes were only made if GHS standards had more stringent values than current P2OASys values. In situations where GHS had additional hazard information, P2OASys added new subcategories and values to the assessment matrix. Subsequently, TURI investigated other chemical assessment tools to determine if using additional sources of chemical hazards endpoints would make the tool more universal.

Once the initial comparison of data points was completed, the biggest remaining obstacle was to convert the P2OASys' cumbersome interface into a web-based interface, making data entry/selection easier. The vision was to reformat P2OASys with an integrative drop-down menu, as shown in Fig. 5.2.

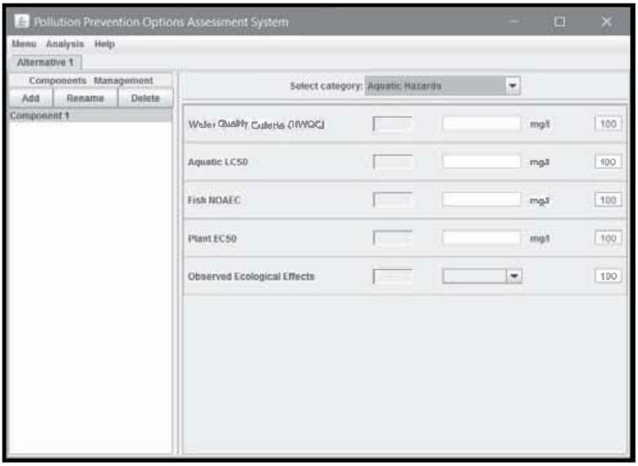

Fig. 5.2. Proposed P2OASys online interface

Following the research project, TURI continued to refine the tool. Several members of the review committee evaluated the categories and subcategories to decide on how best to streamline the set-up. The initial eleven categories were reconfigured into eight sections. A few categories remained unchanged (acute, chronic, and atmospheric) and others were combined to better group the data. Table 5.3 shows the original and proposed changes.

Table 5.3. P2OASys original and new categories

Original categories	Proposed categories
Acute human effects	Acute human effects
Chronic human effects	Chronic human effects
Physical hazard	Physical properties
Aquatic hazard	Ecological hazards
Persistence/bioaccumulation	Environmental fate and transport
Atmospheric hazard	Atmospheric hazard
Disposal hazard	Life cycle factors
Chemical hazard	Process factors
Energy/resource use	
Product hazard	
Exposure potential	

Online tool 2017

During the discussion on how to address the various data types and data inputs, the committee determined to provide the end user with multiple options from which to select. The options would include numerical values, key phrases, GHS phrases, and GHS categories (Fig. 5.3).

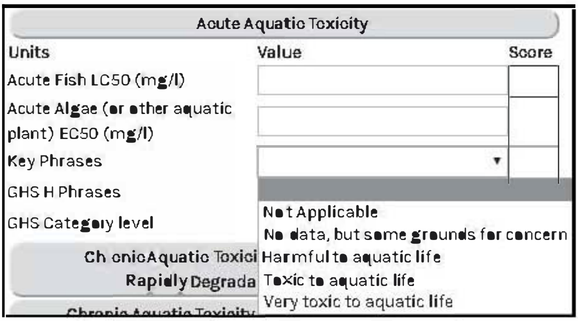

Fig. 5.3. P2OASys on-line, drop-down selection

One drawback of including multiple options for each category is the increase in the number of subcategories from 61 to 150. However, the ease of data entry via drop-down options makes the tool still easier to use than the spreadsheet format.

How P2OASys works

Originally, P2OASys had just one option for the subcategory assessment. With the new set-up, most of the subcategory criteria have multiple options from which to choose. Upon consideration, a decision was made to only choose the worst (highest) value for a subcategory assessment. To illustrate, the original chronic human effects, Fig. 5.4A used only one entry line, whereas the new layout, Fig. 5.4.B, uses eight possible sources for input. The new layout tool would select the highest score entered for this section (IARC Category 10 or GHS Category 10).

Throughout the following scenario, information in P2OASys on trichloroethylene (TCE) will be examined. TCE is a volatile organic compound (VOC), i.e., a chemical that participates in atmospheric photochemical reactions, with a relatively low GWP. Widely used in industrial and commercial processes, TCE poses significant health risks, especially when used for vapor degreasing.

Carcinogen	IARC/EPA class

Fig. 5.4A. Original P2OSys carcinogen subcategory

Chronic Human Effects	9
SubCategory	Trichloroethylene
Carcinogen	10
IARC Category	10
EPACLASS Category	
ACGIH Category	8
OSHACategory	
KeyPhrases	8
GHS H Phrases	8
GHS Category	10
Prop65 Category	8

Fig. 5.4B. New P2OASys carcinogen subcategory

When conducting a full chemical analysis, the more data that can be compared directly, the more accurate the analysis. Nevertheless, in the short-term analysis, using just one subcategory (i.e., the worst-case scenario) for the P2OASys calculation ensures a more conservative, that is, more cautious evaluation.

To calculate the category score, the P2OASys tool selects the highest two scores from the subcategories and averages them. For the chronic human effects category in Fig. 5.5, the highest two values were 10 (carcinogen) and 8 (mutagen, reproductive or other chronic organ effects). The category score would be calculated as 9.

Categories	Trichloroethylene
Acute Human Effects	8
Chronic Human Effects	9
SubCategory	Trichloroethylene
Ca cinogen	10
Mutage /Teratogen	8
Rep oducti e/Developmental	8
Neurotoxicity	6
Respiratory Sensitivity/Disease	
Endocrine System Effects	
Other Chronic Organ Effects	8

Fig. 5.5. P2OAsys category score calculation

The final score for a chemical would then be the average of each category that contains data (Fig. 5.6). For some assessments, if a category has no data, that category would not be included in the final score average. The tool is designed to allow more emphasis on a category depending on the user's needs. This is accomplished using sliding-weight factors.

Categories	Trichloroethylene
Acute Human Effects	8
Chronic Human Effects	9
Ecological Hazards	8
Environmental Fate & Transport	7
Atmospheric Hazard	6
Physical Properties	10
Process Factors	6
Life Cycle Factors	10
Product Score	8
Final Score	8

Fig. 5.6. P2OASys final score

In-house testing

With the new categories and user interface in place, the next step was to beta test the upgraded P2OASys. To do so, several chemicals that had been previously assessed with the original format were re-evaluated with the new framework. One staff member conducted the evaluation to ensure the same level of expertise was used during the new assessment in Table 5.4.

Table 5.4. P2OASys old *vs* new ratings

	Scores		Ranking	
Product	**Old**	**New**	**Old**	**New**
TCE	6.1	7.8	8	8
Potential alternatives				
FLUOSOLV CX	4.6	6.9	5	6
FLUOSOLV CX500	4.0	6.9	2	6
FLUOSOLV FR110	3.8	5.6	1	1
FLUOSOLV NC786	4.6	6.4	5	5
Honeywell PF	4.3	6.1	3	3
Honeywell PF -2A	4.3	5.8	3	2
Vertrel SION	4.6	6.1	7	3

For each chemical evaluated, P2OASys scores were higher (more hazardous) with the new criteria. Both the most hazardous (TCE) and least hazardous (Fluosolv FR110) chemicals remained the same with both versions of P2OASys. Two chemicals had minor changes in their overall rankings (Fluosolv CX, 5 to 6 and Honeywell PF 2A, 3 to 2). One chemical went from low- to the higher-end of the rating (Fluosolv CX 500, 2 to 6) and another candidate chemical moved in the opposite direction (Vertrel Sion, 7 to 3). With most chemicals assessed being within one ranking order from the original rating, the new criteria settings appeared to be evaluating the chemicals appropriately.

What the tool tells you: NOT a definitive value

The P2OASys tool generates a score as a guide in the alternatives assessment process. The score is meant to give the user a way to compare their current process with possible substitutes. The values are not meant to provide the user with a number that would provide a definitive "this is good" or "this is bad" answer. The scores need to be considered in a, *"How does this compare with that?"* mindset. From the evaluations that have been made by TURI staff, a chemical comparison by two people can result in different P2OASys scores. This variance is due to the impact of expert judgement as well as personal biases as to what categories are more important (i.e., weighted).

Another interesting observation is how a chemical's assessment can vary when a single user evaluates the same chemical but uses different safety data sheets (SDSs). SDSs are an integral component of the GHS, intended to provide comprehensive information (chemical properties, hazards, protective measures, etc.) about a substance or mixture for use in the workplace. Differences in the information on SDSs for the same chemical have been previously reported.[6,7] In Fig. 5.7, three SDSs were used for TCE and the scores obtained were 8.4, 8.0, and 8.6. Therefore, it may be worth identifying and using multiple SDSs to conduct a more robust evaluation.

Back Export Category Scores
Export All Scores
Expand All Collapse All

Categories	Hide Trichloroethylene Fisher	Hide Trichloroethylene	Hide Trichloroethylene Sigma
Acute Human Effects	8	8	8
Chronic Human Effects	9	9	9
Ecological Hazards	7	8	9
Environmental Fate & Transport	7	7	7
Atmospheric Hazard	9	6	9
Physical Properties	10	10	10
Process Factors	7	6	7
LifeCycleFactors	10	10	10
Prod ct Score	8.4	8	8.6
FinalScore	8.4	8	8.6

Fig. 5.7. Safety data sheet (SDS) impacts on P2OASys score quality

An example of needing to investigate end points that are relevant to the interests of the user is included when comparing TCE to other solvents with a focus on global warming concerns. Several alternatives to TCE are listed in Fig. 5.8. If the user were to only focus on the product score, their choice of an alternative may overlook negative implications their choice may have on global warming. For example, TCE has a product score above 8, which would imply that the product has several areas of environmental concern. If the end user were to choose an alternative with a product score below TCE's score of 8.4, several choices meet the criteria, including AK 225, 3M HFE 71DE, 1,1,1,3,3-pentafluorobutane and AeroTron CE (5.9, 6.1, 6.3, 6.3, respectively). And when comparing this overall impact on EHS, these choices would seem to make sense. However, when investigating ways to reduce GWP, these same products all have less favorable outcomes. TCE was assessed at a value of 4 for GHGs and the alternatives were at 10, 6, 6, and 6. All of these would be less desirable than TCE.

In the end, the final decision on what would be an acceptable alternative needs to include more than just a quick check of the product score. Specific end points of interest must be investigated to ensure the choice made will not become a regrettable one down the line.

Categories	Trichloro ethylene (Sigma)	AK 225	3M HFE 71DE	1,1,1,3,3-pentafluorobutane	AeroTron CE
Acute Human Effects	8	6	6	6	8
Chronic Human Effects	9	2	8	6	3
Ecological Hazards	9	4	6	2	4
Environmental Fate & Transport	7	6	4	10	10
Atmospheric Hazard	7	10	4	4	4
Greenhouse Gas	4	10	6	6	6
Ozone Depletor	2	10	2	2	2
Acid Rain Formation	2	2	2	2	2
NESHAP	10	2	2	2	2
Physical Properties	10	7	10	10	8
Process Factors	7	4	4	5	6
Life Cycle Factors	10	8	7	7	7
Product Score	8.4	5.9	6.1	6.3	6.3

Fig. 5.8. End-point specific comparison

What to do with the results

The primary goal of alternatives assessment for chemicals of concern is to reduce risks to humans and the environment by identifying safer choices. The intended use of the P2OASys tool is to provide a methodical way to assess TUR process changes. Ideally, the tool will help shed light on environmental, worker, and public health concerns that currently exist, or that may arise during a change of manufacturing process(es). The tool is only intended to provide the user with a safety assessment, one of the pieces of the three-legged alternatives assessment process (technical and financial being the other two); P2OASys does not include performance criteria or economic comparisons. However, by providing the user with a systematic, critical-thinking process about the potential hazards posed by current and alternative processes, better informed decisions can be made.

Concluding remarks

While the terms global warming and climate change are often used interchangeably, climate change is meant to include all those changes (sea level rise, glacial melting, extreme weather events, etc.) that occur because of global warming. Consequently, the future of alternative assessment for high-GWP chemicals is of great importance, including the P2OASys tool.

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CHAPTER SIX

PROCESS IMPROVEMENT IN THE PHARMACEUTICAL INDUSTRY: USING COPPER CATALYSTS

RYAN CONGER[1]

Background

Green chemistry is the design of chemical products and processes that reduce or eliminate the use and generation of hazardous substances. Its practitioners in education, research, and industry apply the following principles in working with chemicals[1] (Table 6.1):

[1] Ryan Conger graduated from the University of New England (UNE) with a Bachelor of Science degree in chemistry in 2017, having worked as a teaching assistant, chemistry tutor and freshman mentor. He also conducted research at UNE with Stephen Fox, Ph.D., synthetizing novel dicopper complexes and exploring their catalytic applications. Mr. Conger presented results from this work at the 254th American Chemical Society (ACS) National Meeting in Washington, DC. Under the auspices of Amy Deveau, Ph.D., he developed a "green" lab curriculum for the honors organic chemistry course, utilizing original procedures for reactions at the forefront of synthetic literature, such as A3 Coupling and "Click Chemistry", along with labs selected from the American Chemical Society (ACS) Journal of Chemical Education. He is currently a graduate student at Boston College pursuing a Ph.D. in chemistry with aspirations of researching inorganic catalysts and their direct applications to the chemical industry.

Table 6.1. Twelve principles of green chemistry[2]

Principle	Description
1. Prevention	It is better to prevent waste than to treat or clean-up waste after it has been created
2. Atom economy	Synthetic methods should be designed to maximize the in-corporation of all materials used in the process into the final product
3. Less hazardous chemical syntheses	Wherever practicable, synthetic methods should be designed to use and generate substances that possess little or no toxicity to human health and the environment
4. Designing safer chemicals	Chemical products should be designed to affect their desired function while minimizing their toxicity
5. Safer solvents and auxiliaries	The use of auxiliary substances (e.g., solvents, separation agents, etc.) should be made unnecessary wherever possible and innocuous when used
6. Design for energy efficiency	Energy requirements of chemical processes should be recognized for their environmental and economic impacts and should be minimized. If possible, synthetic methods should be conducted at ambient temperature and pressure.
7. Use of renewable feedstocks	A raw material or feedstock should be renewable rather than depleting whenever technically and economically practicable
8. Reduce derivatives	Unnecessary derivatization (use of blocking groups, protection/ deprotection, temporary modification of physical/chemical processes) should be minimized or avoided if possible, because such steps require additional reagents and can generate waste
9. Catalysis	**Catalytic reagents (as selective as possible) are superior to stoichiometric reagents**
10. Design for degradation	Chemical products should be designed so that at the end of their function they break down into innocuous degradation products and do not persist in the environment
11. Realtime analysis for pollution prevention	Analytical methodologies need to be further developed to allow for real-time, in-process monitoring and control prior to the formation of hazardous substances
12. Inherently safer chemistry for accident prevention	Substances and the form of a substance used in a chemical process should be chosen to minimize the potential for chemical accidents, including releases, explosions, and fires

This paper focuses on the potential role of copper based catalytic reagents[2] (9th green chemistry principle) in the pharmaceutical industry. The goal is to minimize the enormous amounts of waste, often hazardous, that can be generated by other methods.

Introduction

Many important chemical feedstocks used in the production of fuels and materials are derived from methanol (CH_3OH). The methanol industry generates an estimated 55 billion dollars annually in economic activity creating over 90,000 jobs worldwide.[3] Over 70 million metric tons of methanol were produced globally in 2015, with a projected increase to 100 million metric tons by 2020.[4] Methanol is derived from natural gas obtained through onshore/offshore drilling or hydrofracking. When crude oil is extracted from deposits, natural gas largely consisting of methane (CH_4) is brought to the surface as well.[5] Typically, in areas lacking transportation infrastructure such as pipelines, copious amounts of natural gas are burned off converting methane and oxygen to carbon dioxide and water in a process known as combustion or "flaring." This is done primarily to prevent the release of methane into the Earth's atmosphere (Fig. 6.1). Despite this, flaring is still recognized as a major environmental problem; about 150 billion cubic meter (m^3) of natural gas is flared globally, releasing approximately 400,000,000 metric tons (1 metric ton = 1000 kilograms, kg) of carbon dioxide (CO_2), the primary anthropogenic greenhouse gas (GHG), into the atmosphere per year.[6] This equates to about 30.6 billion dollars of methane flared which is approximately ¼ of the annual United States (U.S.) consumption.

[2] Catalysis is the process of modifying a chemical reaction with the use of a catalyst. This process works with chemicals that already have an existing reaction, and is used to accelerate that reaction for commercial purposes. The catalyst is not consumed by the reaction and can continue to act repeatedly. Consequently, only small amounts of catalysts may be required.

Fig. 6.1. Flare stacks at oil fields in Basra southeast of Baghdad, Iraq

Methodologies

One of the best ways to reduce the environmental impacts of flaring is to implement gas to liquid (GTL) technologies such as steam reforming. Steam reforming converts methane gas and water (H_2O) to carbon monoxide (CO) and hydrogen (H_2), i.e., synthesis gas this process is the first step in the production of methanol and other chemical feedstocks.[6] Steam reforming is energy intensive, usually carried out at temperatures ranging from 1000-1300° Kelvin (K) and pressures between 3-25 atmospheres (atm).[6] Synthesis gas can be converted to methanol in a fixed bed reactor using an alumina pellet catalyst coated with zinc and copper oxides (500°K, 50-100 atm).[7] While these processes are generally efficient on a large scale, they require industrial manufacturing plants and infrastructure which is not ideal for flare stacks dispersed throughout a large area, such as the Bakken Oil Fields in North Dakota (Fig. 6.2). To address this ongoing issue, many chemists strive to find greener GTL technologies, applicable on a small and large scale. One popular approach inspired by bacteria found in nature, is the partial oxidation of methane gas to methanol using oxygen in the Earth's atmosphere.

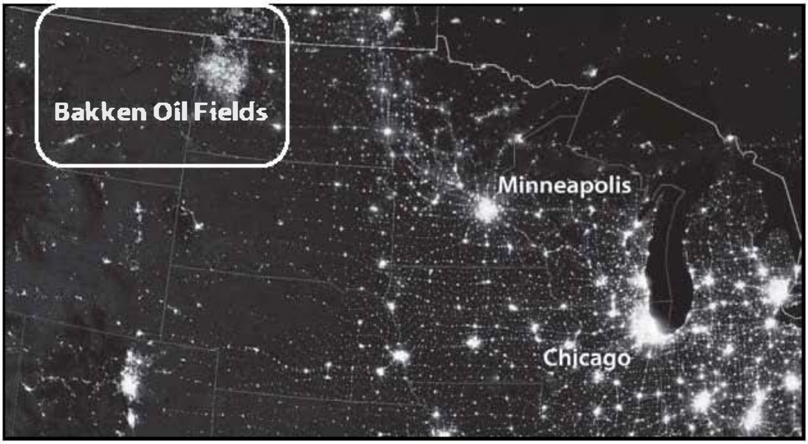

Fig. 6.2. Satellite view of flare stacks at Bakken oil fields in North Dakota, U.S.

Methanotrophic bacteria have evolved to catalytically fix the carbon-hydrogen (C-H) bond of methane via the particulate Methane Monooxygenase (pMMO) enzyme. The partial oxidation of methane occurs at a dicopper center and uses atmospheric oxygen (O_2) under ambient conditions (298°K and 1 atm), producing methanol and water as products of the reaction.[8] In fact, research groups strive to mimic the catalytic behavior of pMMO by designing catalysts and materials capable of similar partial oxidations. Chemical reactions involving the breaking of carbon-hydrogen bonds (C-H activations) provide streamlined routes towards not only basic chemical feedstocks such as methanol, but also complex organic molecules such as pharmaceuticals.

For medicinal chemists to keep pace with the myriad of information derived from biological screenings, there has been an increasing need for reactions that are efficient, versatile, and selective.[9] It is no surprise that reactions involving C-H activations may be some of the most rapidly growing and well-studied reactions throughout industry and academia.[9,10,11] In comparison to platinum group metals (PGMs), advantages of copper include its abundancy, low-toxicity, and low-cost.[11] In some cases, copper catalysts may even provide suitable alternatives to PGMs.

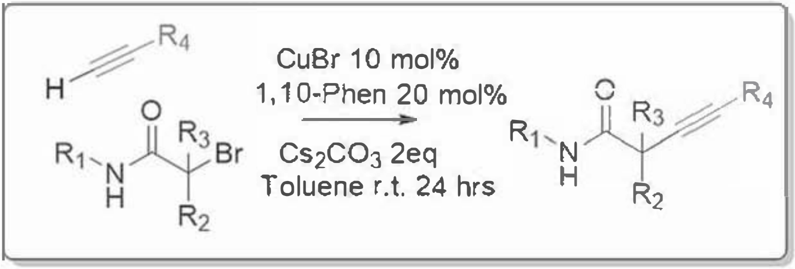

Fig. 6.3. Sonogashira-type coupling of alpha-bromo amides

Recently, Nishitaka developed a method for Sonogashira-type couplings between terminal alkynes and alpha-bromo amides using a copper catalyst (Fig. 6.3).[11] The relevance of this reaction is quite high given that the amide functional group occurs in over 50% of medicinal chemical patents on the IBEX database.[12] Coupling of the alkyne and tertiary carbon generates a quaternary carbon center which are generally considered challenging synthetic targets. Moreover, copper catalyzed procedures can be applied to heteroatom alkylations/arylations, C-C bond formations, and heterocycles formations which constitute a total 42.8% of reactions used in medicinal chemistry (Fig. 6.4).[10]

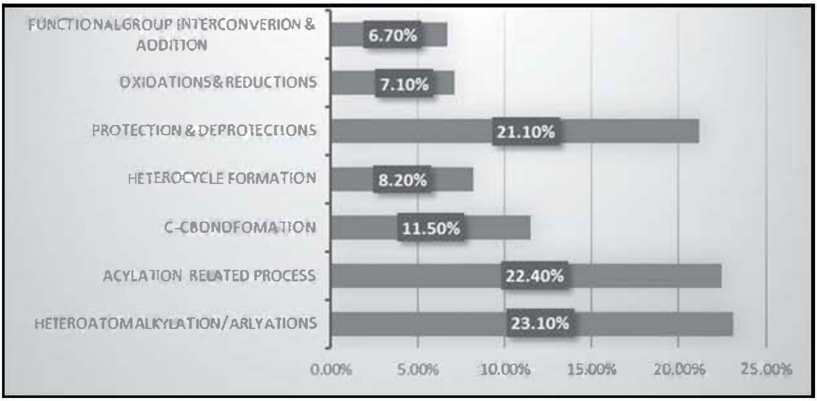

Fig. 6.4. Analysis of reactions used in medicinal chemistry manuscripts (2008-2009)

Another advantage of copper is its ability to activate C-H bonds of terminal alkynes. Often referred to as "click chemistry", copper-catalyzed azide-alkyne cycloaddition (CuAAC) is considered one of the most powerful two-component coupling strategies in modern synthetic chemistry (Fig. 6.5). Due to its high functional group tolerance, CuAAC can be used to functionalize membrane surfaces and couple peptides. Additionally, CuAAC can be carried out under mild conditions: reactions often require low catalyst loading, proceed at room temperature, and in many cases reach completion in under several hours.

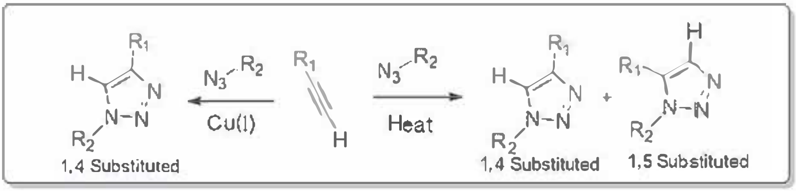

Fig. 6.5. Copper catalyzed azide-alkyne cycloaddition "Click Chemistry". Under thermal conditions (absence of catalyst) the reaction gives a mixture of the 1,4 and 1,5 substituted triazoles. CuAAC gives only 1,4 substituted triazoles under ambient to mild conditions.

In addition to CuAAC, copper catalysts are especially useful in multicomponent reactions (MCRs). MCRs are cascade chemical transformations that combine three or more reactants to assemble a common product. In most cases, MCRs provide greener alternatives to multistep syntheses because they are carried out in a single reaction vessel thereby reducing solvent waste. Additionally, MCRs are much more economical than multi-step syntheses and can save valuable time and recourses spent on the purification and isolation. One challenge of MCRs is tailoring the reaction conditions in such a way to maximize yields and prevent the formation of unwanted biproducts. One example of an MCR where the conditions are well-established is A^3 coupling.

A^3 coupling is a multicomponent, condensation reaction between an aldehyde, alkyne, and amine to give propargylamines (Fig. 6.6). These compounds are important precursors to many pharmaceuticals and valuable building blocks in natural product synthesis.[12] By varying the functionalities of the reactants, many propargylamine intermediates can undergo further transformations into a variety of biologically active heterocycles. For instance, A^3 coupling can be applied to the one step synthesis of pharmaceuticals such as Zolpidem (Ambien).

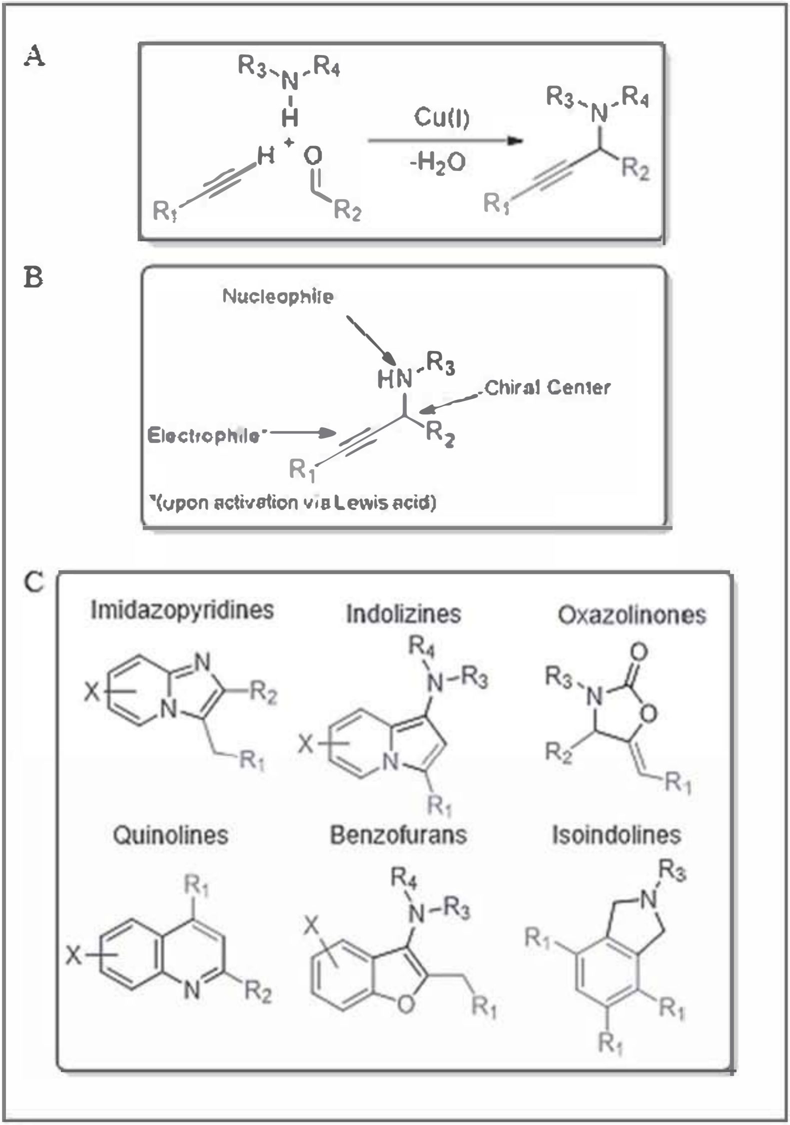

Fig. 6.6. Generic scheme for A^3 coupling (A), reactive sites in propargylamines (B), and biologically active heterocyclic frameworks prepared from A^3 coupling (C) [12]

Concluding remarks

In conclusion, copper catalysts are "greener" than PGMs and present many relevant applications in reactions used in medicinal chemistry. Furthering our understanding of copper-chemistry will incentivize research installations to use copper catalysts to accelerate their drug development efforts while diminishing substantial amounts of hazardous waste. Specifically, advances in catalysis should address:

> "<the> growing concerns of global climate changes in order to minimize pollutants during the process development of drug synthesis."[13]

Future developments may well include a comparison of old and new processes based on a life cycle assessment (LCA) approach, which identifies the material, energy, and waste associated with both processes. LCAs determine environmental impacts and potential improvements. One such method was developed by the United Nations Intergovernmental Panel on Climate Change, IPCC GWP 100a, which analyzes global warming potentials expressed as kg CO_2 equivalents. Thus, the sustainability of the two manufacturing processes can be compared for risks and benefits.[14]

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SECTION II.

CONCERNING PEOPLE

CHAPTER SEVEN

DEATH BY DEGREES

SYDNEY R. SEWALL, MD MPH[1]
BOARD PRESIDENT, PSR MAINE

Introduction

In 2000, Physicians for Social Responsibility Maine Chapter (PSR Maine) in the United States (U.S.), a statewide nonprofit organization comprised of several thousand medical and healthcare professionals and advocates, published a groundbreaking report entitled ***Death by Degrees: The Emerging Health Crisis of Climate Change in Maine*** *(DbD)* that focused on the impact of climate change on public health. In 2015, PSR Maine released the updated version – ***Death by Degrees: The Health Crisis of Climate Change in Maine.***

Representatives from PSR Maine contributed to the International Technical Workshop on Climate Risk both in 2016 and 2017. A summary of the 2016 presentation was incorporated as a chapter in the book generated

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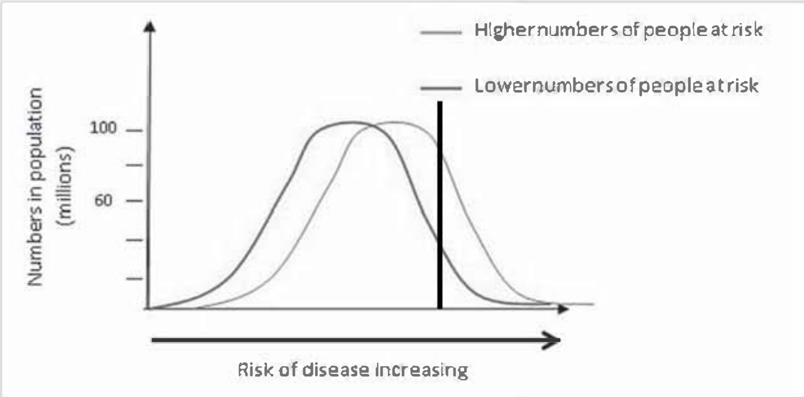
[1] Dr. Sydney Sewall, MD, MPH was educated at Harvard and University of Cincinnati, and has been working as a Pediatrician since graduating from medical school in 1975. After serving in the Indian Health Service in Arizona, he moved to Maine in 1982 and has lived here since, raising two now-adult children with his spouse of 43 years. Medical activities have always included teaching either residents or medical students and in 2016, he left his pediatric practice to join the faculty at the Maine Dartmouth Family Practice Residency. Dr. Sewall has been involved with Physicians for Social Responsibility Maine Chapter since 1990. Other medical activities have included membership on the board of Maine American Academy of Pediatrics (former president), chairman of MaineGeneral Hospital's Quality Council (and former Chief of Staff), and Pediatric Advanced Life Support instructor. Dr. Sewall has a special interest in epidemiology, and earned an MPH in 1997 while working part time.

by that event.[2] The 2017 presentation updated and expanded the content of the original discussion, and is summarized in this chapter.



https://upstreamthinking.wordpress.com/geoffrey-roses-prevention-theory/

Fig. 7.1. Diagram illustrating the public health perspective (credit to Geoffrey Rose)

Climate change as a public health issue

The public health perspective approaches disease rates as the outcome of a set of interacting risk factors impacting the overall population. This analysis can, at times, afford the health care system the ability to greatly reduce disease rates through public information campaigns, voluntary changes from industry, or legislation. Examples include the "Back to Sleep" campaign which reduced Sudden Infant Death Syndrome (SIDS) by half, labeling sodium content of foods to reduce hypertension, and the elimination of leaded gasoline.

While clinical medicine deals with individual patients and their problems or risk factors, public health measures target the actual "determinants of disease" that contribute to individuals' health status. As depicted in Fig. 7.1, the goal is to SHIFT the bell-shaped curve of population risk to the left, so that the area under the tail on the far right (representing those with disease) is reduced.

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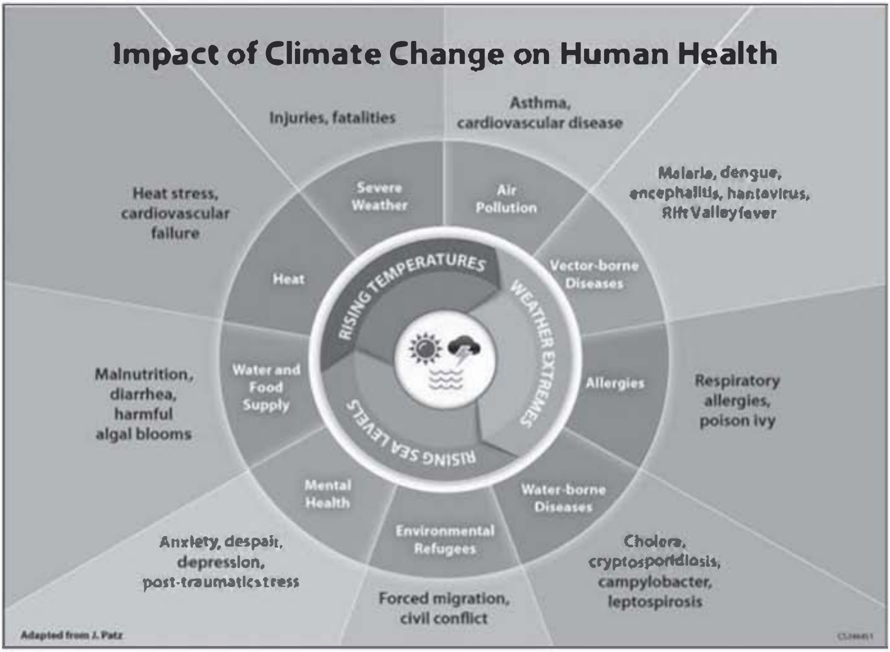
[2] D'Andrea, Karen A., *Death by Degrees: The Health Crisis of Climate Change in Maine, U.S.*, **Demystifying Climate Risk Volnme I: Environmental, Health and Societal Implications** (LeBlanc, C. ed., Cambridge Scholars Publishing, 2017).

Climate change, in this model, creates conditions which shifts the curve to the RIGHT (increasing risk) for a number of conditions. Fig. 7.2 describes these categories of disease that are impacted.



http://toolkit.climate.gov/image/505
Fig. 7.2. U.S. climate resilience toolkit

The remainder of this chapter will explore each wedge of this circle models predict and epidemiologic data supports the concept that warming, rising sea levels, and weather extremes combine to impair respiratory health, change infectious disease patterns, and lead to both physical and mental health injuries. As described in Table 7.1, the causal pathway between climate change and health outcomes has a number of intermediary steps.

Table 7.1. Categories of climate-change risks to health, according to causal pathway

Risk Category	Causal Pathway
Primary	Direct biologic consequences of heat waves, extreme weather events, and temperature-enhanced levels of urban air pollutants
Secondary	Risks mediated by changes in biophysically and ecologically based processes and systems, particularly food yields, water flows, infectious-disease vectors, and (for zoonotic diseases) intermediate-host ecology
Tertiary	More diffuse effects (e.g., mental health problems in failing farm communities, displaced groups, disadvantaged indigenous and minority ethnic groups)
	Consequences of tension and conflict owing to climate change--related declines in basic resources (water, food, timber, living space)

From: McMichael – N Engl J Med 2013;368:1335-43.

Respiratory health

The American Lung Association's *2014 State of the Air* report described groups at increased risk from poor air quality in Maine. Out of our total population of 1.3 million, we have over 220,000 persons over 65. Twenty-five thousand children have asthma, along with 120,000 asthmatic adults, plus another 80,000 adults with chronic obstructive pulmonary disease (COPD). When you add in persons with heart disease and diabetes, you find that a substantial proportion of our residents are at increased risk of health complications related to pollution.

The Maine Department of Environmental Protection (DEP) uses a scoring system to warn citizens about unhealthy air. There were 17 days in 2013 where one or more areas in Maine were forecasted in the "moderate" (yellow) zone (where at-risk individuals should consider reducing strenuous activity), and another six days were considered "unhealthy for sensitive groups" (orange).

Air quality dynamics are complex. While clean air legislation has reduced the emission of ozone precursors from smokestacks, higher temperatures promote the chemical reactions that convert precursors into ozone, reversing the effects of legislation. Wind patterns play a role since lack of vertical mixing inhibits dilution of ground level concentrations.

Because ozone (O_3) is an irritant, O_3 levels are associated with emergency room (ER) and hospital admissions for respiratory ailments, and premature death especially in vulnerable populations. Thus: the higher temperatures and unpredictable wind patterns expected with climate change will push the population curve to the right and increase population morbidity from respiratory disease. The particulate matter (PM) level in the air, $PM_{2.5}$, is similarly affected with precipitation and atmospheric mixing helping to lower levels, where prolonged dry periods can have the opposite effect.

There are multiple studies relating PM and ozone to cardiovascular events due to their inflammatory nature (N Engl J Med 2017; 376:2591-2592). Note in Fig. 7.3 that the Northeast region of the U.S. is expected to have an increase in ozone related mortality over time, rivaling the midwestern industrial heartland.

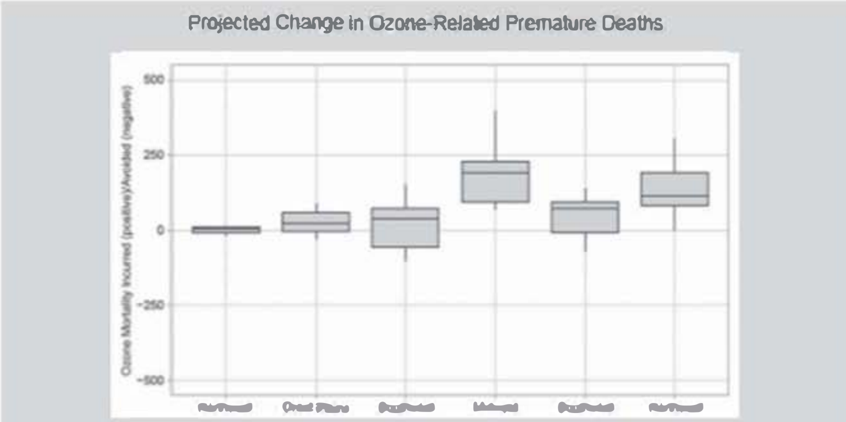


Figure 3. Projected change in ozone-related premature deaths from 2000 to 2030 by U.S. region and based on CESM/RCP8.5. Each year (2000 and 2030) is represented by 11 years of modeled data. Ozone-related premature deaths were calculated using the risk coefficient from Bell et al. (2004).[34] Boxes indicate 25th, 50th, and 75th percentile change over 11-year sample periods, and vertical lines extend to 1.5 times the interquartile range. U.S. regions follow geopolitical boundaries shown in Figure 2. (Figure source: Fann et al. 2015)[14]

Journal of the Air and Waste Management Association, 65, 570-580. http://dx.doi.org/10.1080/10962247.2014.996270

Fig. 7.3. Ozone-related health effects

The defining features of asthma are cough and shortness of breath due to bronchospasm. While air pollution itself can be a trigger, it also can interact with allergen exposure in susceptible individuals to increase the percent of the population having symptoms. An extensive literature documents the relationship between air quality and ER visits. Additionally, the density and duration of the pollen season in temperate climate zones is predicted to increase as illustrated in Fig. 7.4. Maine is at the latitude where we already experience an extra 2-3 weeks of allergy season.

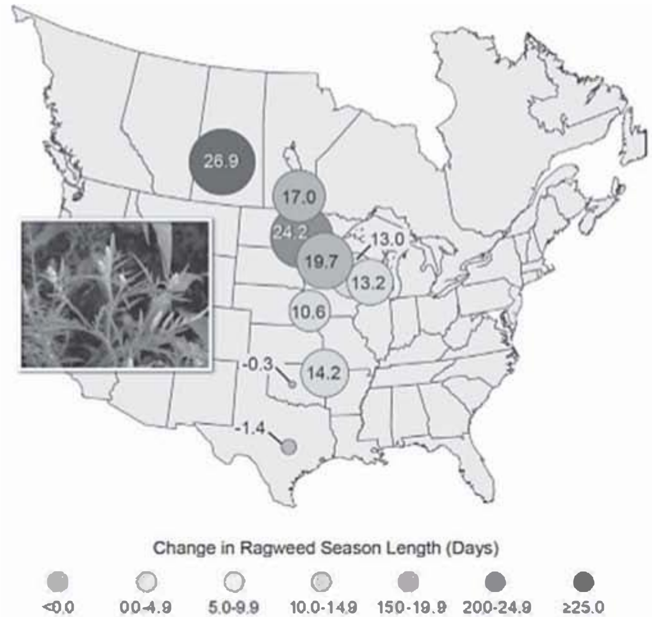


Figure 4: Ragweed pollen season length has increased in central North America between 1995 and 2011 by as much as 11 to 27 days in parts of the United States and Canada, in response to rising temperatures. Increases in the length of this allergenic pollen season are correlated with increases in the number of days before the first frost. The largest increases have been observed in northern cities. (Figure source: Melillo et al. 2014. Photo credit: Lewis Ziska, USDA).

Fann, N., T. Brennan, P. Dolwick, J.L. Gamble, V. Ilacqua, L. Kolb, C.G. Nolte, T.L. Spero, and L. Ziska, 2016: Ch. 3: Air Quality Impacts. The Impacts of Climate Change on Human Health in the U.S.: A Scientific Assessment. U.S. Global Change Research Program, Washington, DC, 69–98. https://s3.amazonaws.com/climatehealth2016/low/ClimateHealth2016_03_Air_Quality_small.pdf
Fig. 7.4. Ragweed pollen season lengthens in U.S. and Canada

Thus, we can expect individuals with "extrinsic asthma" (triggered by allergens) to have longer periods where symptom control can be challenging

In addition to long term trends, weather extremes also can contribute to respiratory disease. Uncontrolled fires spew particulate matter in the air, as experienced in California numerous times this decade (https://www3.epa.gov/airnow/wildfire_may2016.pdf). Conversely, prolonged rainy period and flooding produce increased mold accumulation in homes.

Vector borne diseases[3]

What used to be a medical curiosity in Maine has become a routine event over the last decades – the diagnosis of Lyme disease. As the range of the offending tick has spread and interactions with humans have increased, the number of cases has skyrocketed. In addition, the same deer tick species can carry the bacteria that cause Ehrlichiosis and Anaplasmosis, or a parasitic organism that causes Babesiosis. All of these illnesses are treatable but debilitating, especially in persons with weakened immune systems.

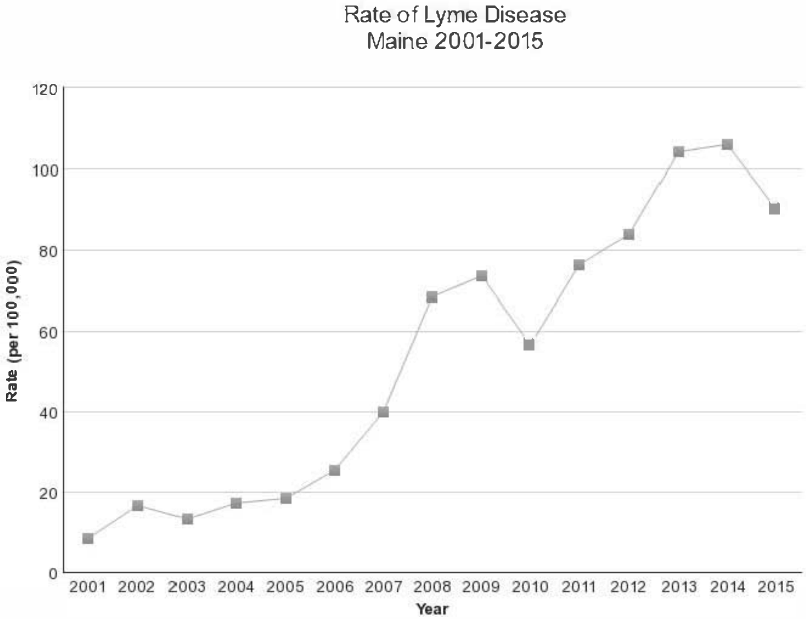


Fig. 7.5. Maine Center for Disease Control and Prevention (CDC) data for Lyme Disease

The Maine experience parallels the trend elsewhere in the U.S. Northeast and upper Midwest.

[3] Vector borne diseases are human illnesses caused by parasites, viruses, and bacteria that are transmitted by mosquitoes, ticks, lice, etc. Taken together, the major vector borne diseases account for approximately 17% of all infectious diseases (United Nations World Health Organization).

Maine is also not immune from mosquito borne illnesses. While domestic cases of Zika are not an issue at this time, the southern tip of the state is within the range of the mosquito carriers. West Nile virus was first identified in the state in 2013, related to climate-related changes in bird migration patterns with mosquitoes carrying the virus from the avian natural host to humans. Our first human case of Eastern Equine Encephalitis presented in 2014, with dozens of animal cases reported over the last decade. Table 7.2 points out the trend towards increasing numbers in a variety of vector-borne diseases in the U.S. (Impact of Climate Change on Health – health2016.globalchange.gov).

Table 7.2. Summary of reported case counts of notifiable vector-borne diseases in the U.S.

Diseases	2013 Reported Cases	Median (range) 2004-2013[b]
Tick-Borne		
Lyme disease	36,307	30,495 (19,804 38,468)
Spotted Fever Rickettsia	3,359	2,255 (1,713 4,470)
Anaplasmosis/Ehrlichiosis	4,551	2,187 (875 4,551)
Babesiosis[b]	1,792	1,128 (940 1,792)
Tularemia	203	136 (93 203)
Powassan	15	7 (1 16)
Mosquito-Borne		
West Nile virus	2,469	1,913 (712 5,673)
Malaria	1,594	1,484 (1,255 1,773)
Dengue[b]	843	624 (254 843)
California serogroup	112	78 (55 137)
Eastern equine	8	7 (4 21)
St. Louis encephalitis	1	10 (1 13)
Flea-Borne		
Plague	4	4 (2 17)

State Health Departments are required by law to report regular, frequent, and timely information about individual cases to the CDC in order to assist in the prevention and control of diseases. Case counts are summarized based on annual reports of nationally notifiable infectious diseases.[1,2,3,4,5,6,7,8,9,10]

[b] Babesiosis and dengue were added to the list of nationally notifiable diseases in 2011 and 2009, respectively. Median and range values encompass cases reported from 2011 to 2013 for babesiosis and from 2010 to 2013 for dengue.

Waterborne illnesses

Waterborne illnesses are an issue after periods of flooding or excessive rainfall. Sewage processing has limited capacity, and separation of rainwater runoff from wastewater is not always possible. Agricultural runoff into surrounding waterways is an additional concern in some parts of the country. In Maine, the shellfish industry is periodically hit with widespread closures due to toxigenic algae contamination (related to warming oceans as well as runoff) along with local closures due to sewage overflow.

Heat illness

Heat illness is a direct result of climate change, as evidenced by the tragic deaths in a Florida nursing home that lost power during the 2017 hurricane. High risk populations include the elderly, persons on medications that impair compensation, infants, cardiovascular disease patients, et al. The spectrum of illness ranges from heat exhaustion and mild dehydration to heat stroke – where the body's homeostatic mechanism has broken down completely, delirium or coma ensue, and the body temperature rises to 106° Fahrenheit (F). The European heat wave of 2003 led to over 30,000 confirmed deaths (**AJPH 94:9**). The trend in heat related hospitalizations has been in an upward direction in the U.S. over the last decade (MMWR 63:13).

Mental health

Mental health concerns relate to climate also in obvious ways. The aftermath of Hurricane Katrina has been described as a "disruption of normalcy" – repeated in 2017 in Houston with Hurricane Harvey, and in Puerto Rico after Hurricane Maria. Entire communities, neighborhoods and individual lives were forever changed in ways most of us could never imagine. Loss of homes, jobs, food supplies, and power disrupt normal routines – with associated increases in ER visits, hospitalizations and acute and chronic illnesses. In Puerto Rico, crisis managers were overwhelmed by both the number of calls to their suicide prevention hotlines, as well as the number of suicide attempts (USA Today).

Sociologic impact

As an organization whose fundamental goal is to prevent wars, PSR is also concerned about the potential increase in conflicts driven by climate change.

Large-scale degradation of land and water resources, along with disturbances of local ecosystems, may lead to the scarcities of staple foods that drive political upheaval. The potential for conflicts between states over resources looms large over our future. While local measures towards adaptation might modify this risk, the long-term solution (push the bell-shaped curve in the right direction) involves reducing the global production of greenhouse gases (GHGs) – the biggest challenge of the 21st century.

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CHAPTER EIGHT

TRADITIONAL KNOWLEDGE AND CLIMATE CHANGE CHALLENGES: ANAMBRA STATE, NIGERIA CASE STUDY

CHIZOBA CHINWEZE[1]

Abstract

The study area, Anambra State, is located in the southeastern part of Nigeria in West Africa, with a landmass of 44,116 square kilometers (km^2) and a human population of about 4,182,032. Soil erosion constitutes the major ecological challenge of the state.

With increases in precipitation levels and intense flooding, as indicated by Intergovernmental Panel on Climate Change (IPCC) fourth assessment report for the United Nations Framework Convention on Climate Change (UNFCCC), resultant soil transport caused severe gully erosion of this area. Over 40% of the total land area in the state is currently severely eroded. Anthropological factors also accelerate the development and expansion of gullies, with attendant human vulnerability.

This paper classifies the gully erosion/flooding in the area according to their severity and socioeconomic impact. It further analyses their consequence and human vulnerability in the face of climate change challenges and the

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limited adaptive capacity of local people through the application of traditional knowledge.

Study area

Anambra State in the southeastern part of Nigeria lies between latitude 5° 42′ North (N) and 6° 47′N and longitude 6° 37′ East (E) and 7° 23′ E. The state is made up of 127 communities divided into 22 local government areas with a population of 4,182,032 million people in a land mass of 44,116 km^2 (Fig. 8.1).

The study area lies within the tropical region. The area is influenced by two climatic seasons, the dry and wet seasons. The wet season starts mid-January/February and is in full swing by March, ending in November, with a break in August. The average annual rainfall is about 1800 millimeters (mm) concentrating between the months of May and November. The dry season lasts for four or five months.

Fig. 8.1. Map of Nigeria showing the study area – Anambra State

The prevailing winds are the southwesterlies which bring rains during the wet months, and the northeasterlies or northwesterlies which occur during the dry months and are known for the hazy, harmattan[2] conditions. The wind speeds are low, less than 2 miles (4 knots) per hour, throughout the year.

The relative humidity is high all the year round; 80% at night and between 65-75% during the day. The ambient air temperature varies between 25° Celsius (C) and 32°C. The mean daily temperature is 28°C, while the average annual temperature is 27°C. However, the temperature can go up to 32°C during the hot periods of the year.

The main drainage system for the state is the Anambra River which empties into River Niger. The natural flow patterns of the river and streams in the area form a kind of drainage pattern in the area. The area is well drained. In general, the topography of the area can be described as; namely, the uplifts and the basins of sedimentation.

The soil type is deep red, porous, and unconsolidated. The land surface is covered with vegetation. There are various trees species of commercial value found within the area.

Farming (subsistence agriculture)[3], trading, and small-scale industries are the main sources of economy of the state.

Climate facts and risks

Climate change is an emerging reality with immense concern to the international community as it is one of the factors that adversely affect the actualization of the UN Sustainable Development Goals (SDGs). The term 'climate change' means any change in climate over time, whether due to natural variability, or, as a result of intense human activities. Africa has been identified as the most vulnerable to the impacts of climate change,[1] with dangers of extreme events, aridity, flooding, shifts in rainfall, sea level rise, and between 1.5°-2°C warming; given its geographical position, limited adaptive capacity, exacerbated by widespread poverty and the existing low levels of development.

The climate facts[2] about Africa is that by 2050, the average temperatures in Africa are predicted to increase by 1.5°-3°C and will continue further upwards beyond this time. Warming is very likely to be larger than the global annual mean warming throughout the continent and in all seasons,

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[2] A dry, dusty easterly or northeasterly wind on the West African coast, occurring from December to February.

[3] For more information on this topic, see chapter five, "*Climate Change and Sub-Saharan Africa: Agriculture and Food Security Nexus*" by C. Chinweze in **Demystifying Climate Risk Volume I: Environmental, Health, and Societal Implications** (LeBlanc, C. ed., Cambridge Scholars Publishing, 2017).

with drier subtropical regions warming more than the moister tropics. Ecosystems are critical in Africa, contributing significantly to biodiversity and human well-being. Between 25% and 40% of mammal species in national parks in sub-Saharan Africa will become endangered. There is evidence that climate is modifying natural mountain ecosystems via complex interactions and feedbacks.

By 2080, an increase of 5% to 8% of arid and semi-arid land in Africa is projected under a range of climate scenarios. Africa will face increasing water scarcity and stress, with a subsequent potential increase of water conflicts as almost all of the 50 river basins in Africa are transboundary.[3] Agricultural production relies mainly on rainfall for irrigation and will be severely compromised in many African countries, particularly for subsistence farmers in sub-Saharan Africa.[4] Africa is vulnerable to a number of climate sensitive diseases including malaria, tuberculosis, and diarrhea[5] and other stresses and vulnerabilities such as HIV/AIDS, conflict and war[6], leading to risk of malnutrition for adults and children and poor health.[7]

Sea level rise has the potential to cause huge impacts on the African coastline. According to a 2005 estimate, the continent has close to 320 coastal cities, with more than 10,000 people, and an estimated population of 56 million people (2005 estimate) living in low-elevation (<10 meters), coastal zones. Towards the end of the 21^{st} century, projected sea level rise will affect low-lying coastal areas with large populations. About 30% of Africa's coastal countries shall be at the risk of partial or complete inundation due to accelerated sea level rise, which will probably increase the high socio-economic and physical vulnerabilities of coastal cities. Future sea level rise also threatens lagoons and mangrove forests of both eastern and western Africa. The projection that sea-level rise could increase flooding, particularly on the coasts of Eastern Africa, will have implications for health. Increases in precipitation will also increase the incidence of flooding.

Flood and erosion challenges in Anambra State

Anambra is exposed to intense precipitation and consequently flooding leading to ecological challenges, particularly soil erosion. The topography of most of the area consists of pronounced rolling, long, steep slopes (Fig. 8.2A and 8.2B) that enhances runoff velocity and results in the washing off of top soil, leading to soil erosion and flooding on the low-lying terrains (Fig. 8.3A and 8.3B). The major drainage channel of the area is the River Niger and a few tributaries such as Omabala River, Oyi River, and Ezu River.

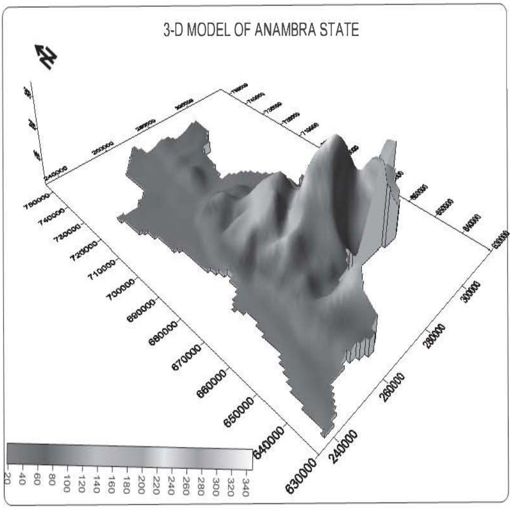

Fig. 8.2A. 3-D Model of the study area

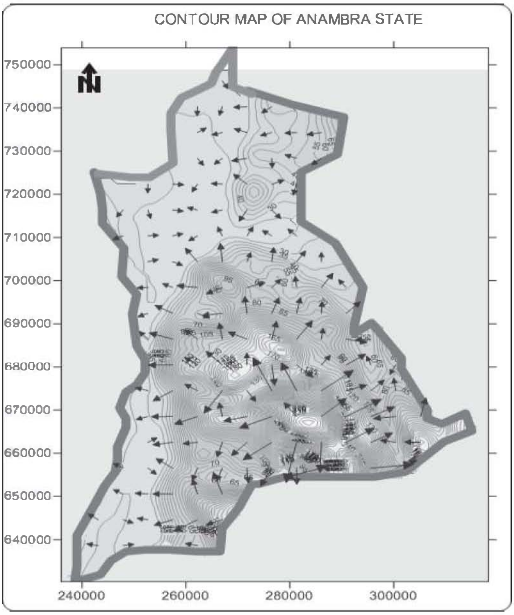

Fig. 8.2B. Contour/flow model (Source: reproduced from Emmanuel et al.[8])

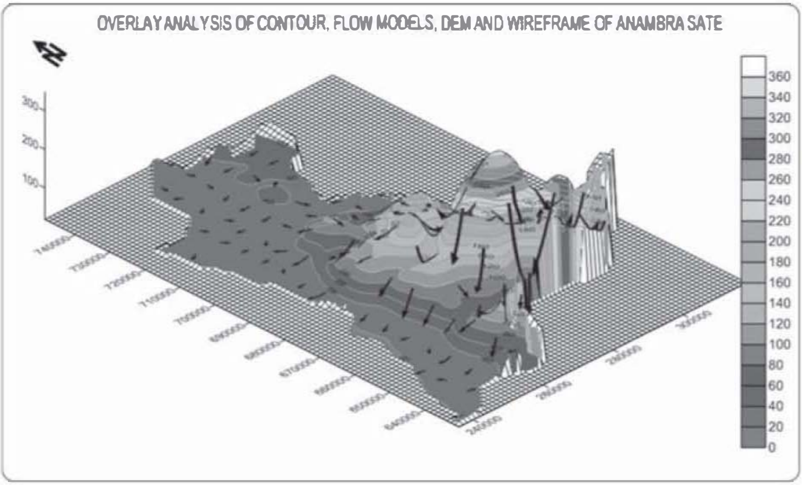

Fig 8.3A. Overlay analysis of wireframe Digital Terrain Model (DTM) and flow models of Anambra[8]

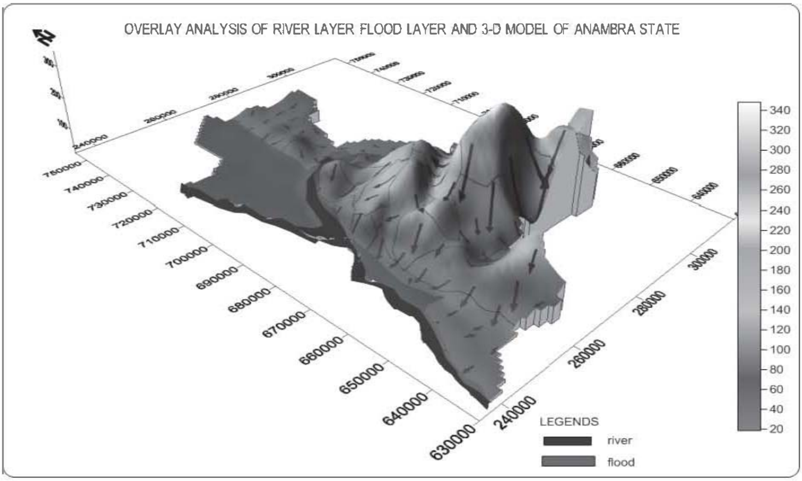

Fig. 8.3B. A 3-D overlay analysis of the river layer, flood layer, and DTM[8]

Risk classification and vulnerability assessment

The 2014 IPCC report on Impacts, Adaptation, and Vulnerability highlights the concept of risks (Fig. 8.4) and by its definition, the term risk is used primarily to refer to the risks of climate-change impacts. In this concept, vulnerability constitutes one of the factors that shape the level of risk for a particular location and societal group. The exposure to climate-risk related factors, such as intense precipitation as well as the degree to which a society is affected (hazard), contribute to the potential impacts that climate change will have on the society. Risk and uncertainty are central to assessing the consequences of climate change and formulating response strategies.[9] Various components contribute to climate vulnerability, including: (1) exposure, (2) sensitivity, (3) potential impacts, and (4) adaptive capacity.

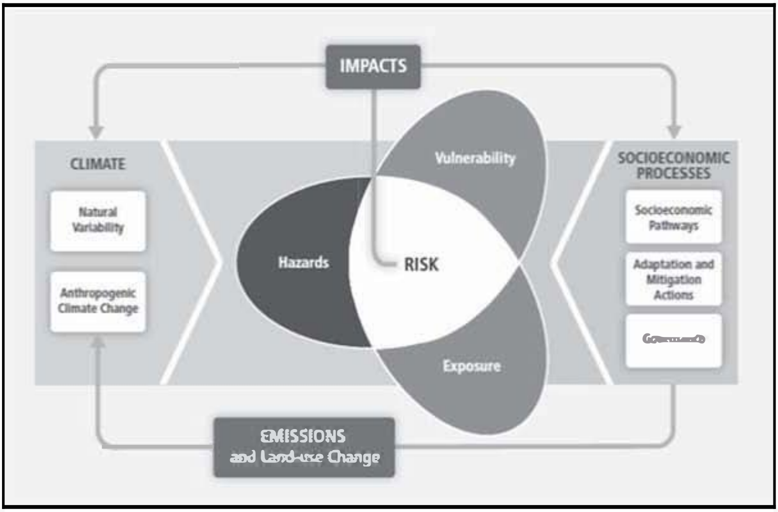

Fig. 8.4. IPCC 2014; Impacts, adaptation, and vulnerability: New perspective on risk and vulnerability[1]

The risk classification of gullies formed as a result of soil erosion, in the state are as shown in Fig. 8.5.

- 1769.52 km^2 of the state, or 40.1% is severely gullied;
- 1316.58 km^2 or 27.8% is moderately gullied; and
- 1416.12 km^2 or 32.1% is mildly gullied.

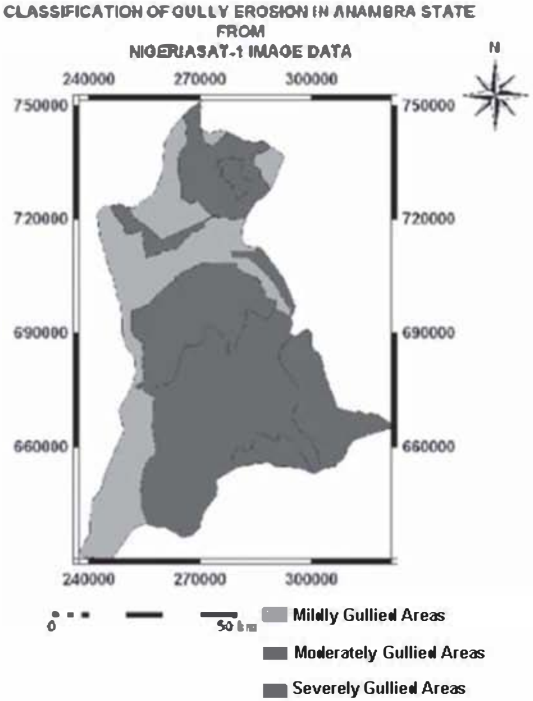

Fig. 8.5. Image classification of gully erosion severity in Anambra State

Given that the population density of the state is approximately 900 persons per km^2, the population exposed to gully hazard are calculated to be:

- 1,592,568 persons or 38.08% of the population live in the area identified as severely gullied; and are therefore highly exposed to the risks of gully erosion;
- 1,184,922 persons or 28.33% of the population live in the area marked as moderately gullied, thus they are moderately vulnerable to the risk of gully erosion; and
- 1,274,508 or 30.47% of the population living in the area marked as mildly gullied and are mildly exposed or vulnerable to the gully erosion hazards.

The flood hazard map (Fig. 8.6) also indicates that populations living in the low-lying terrain are most vulnerable to flooding.

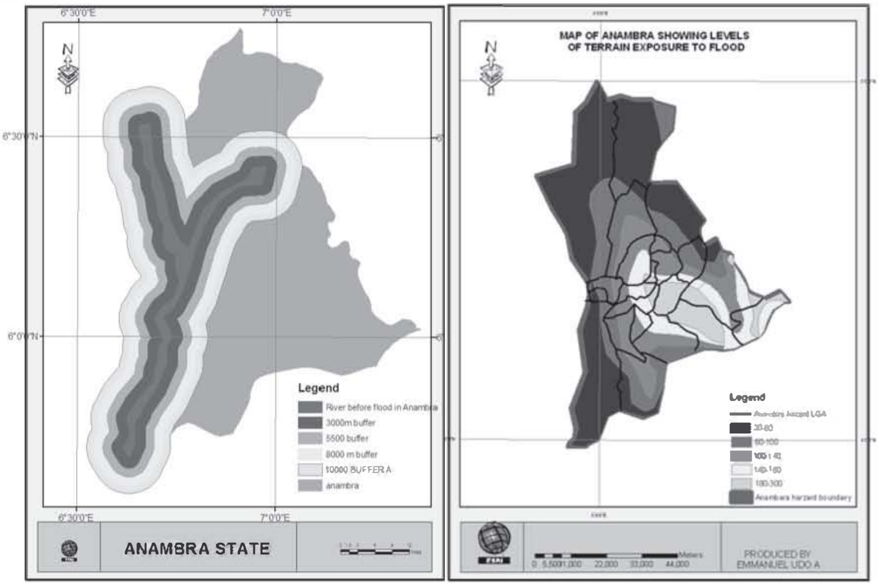

Fig. 8.6. Flood hazard map[8]

The consequence of gully erosions and flooding in Anambra State include: (1) displacement of communities, (2) loss of lives, (3) loss of farmland, and (4) the destruction of houses, highways, and infrastructural development.

Traditional knowledge in managing climate risks

Traditional knowledge is increasingly being recognized as valuable for handling climate risk. Traditional ecological knowledge (TEK) has been characterized as:

> "a cumulative body of knowledge, practice, and belief, evolving by adaptive processes and handed down through generations by cultural transmission, about the relationship of living beings (including humans) with one another and with their environment."[10]

Traditional knowledge is therefore useful in defining earlier environmental baselines, identifying impacts that need to be mitigated, providing observational evidence for modelling, providing technologies for adapting, and for identifying culturally appropriate values for protection from direct impacts or from the impacts of adaptation measures themselves[11].

More than anywhere else on the globe, the sub-Saharan Africans relied on nature for sustenance. Millions of families depend on natural resources for sustenance.[12] As such, they are the custodians of these resources. Traditional knowledge, which is handed down generations is interwoven with culture, religious beliefs, practice and community-based decision-making process. It has made for good forest management, conservation of ecosystem services, biological diversity and identification/preservation of genetic resources, as it is understood in science and international climate policy. This dependence on and relationship with nature has helped the people develop skills acquired over the years to manage profitable natural resources. In the erosion prone zones of the state, the locals, through indigenous knowledge, use native plant species and local soil management practices to manage soil erosion and reduce the escalation of gullies within their capabilities. In the flood plains, the people employ forest governance which has cultural, religious, and spiritual significance to contain flooding. It is worthy to note that the adaptive capacity of the people is low due to (1) poverty, (2) limited access to technologies, as well as (3) poor policy and institutional frameworks. Adaptive capacity is reflective of resiliency, such that a resilient system has the capacity to prepare for, avoid, moderate, and recover from climate-related risks and/or change.[13] *The combination of high potential impact and low adaptive capacity makes the state highly vulnerable to climate change and climate variability.*

Conclusion

The land management measures employed by the people which are traditionally-based seem inadequate to address the magnitude of climate-induced erosion and land degradation in the area.

Therefore, in order to enhance their adaptive capacities, funds and advanced technology shall be made available to assist the state and the citizenry as gully erosion control is an expensive venture.

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CHAPTER NINE

MARITIME PORTS: IMPACTS ON CLIMATE CHANGE

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PHILLIP E. BARNES, PH.D.[3]

Abstract

The shipping industry continues to expand: transport of cargo to maritime ports for distribution to a growing population is the lifeblood of global trade. Maritime trade begins with overland transportation, usually truck or rail, either delivering cargo to, or receiving cargo from, a maritime port. The

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[3] Phillip Barnes holds the title of Distinguished Research Professor Emeritus in the Environment and Sustainability Program with the School for the Earth, Ocean and Environment at the University of South Carolina. Barnes has twice been named a Fulbright Scholar to research the integration of international management systems in Morocco and in 2018 was placed on the Fulbright Specialist Roster. He holds an International Ph.D. in Cleaner Production, Industrial Ecology & Sustainable Development from Erasmus University, the Netherlands.

movement of cargo in a port involves the following activities: (1) the shipping industry delivers and receives cargo, (2) port operations load and unload cargo, and (3) the overland transport delivers the cargo to be loaded on a ship, or, the overland transport is loaded with cargo the ship has delivered to the port, for delivery to customers. Therefore, as will be presented, the maritime port is a hub of activity in which the movement of cargo results in the release of tons of greenhouse gas (GHG) emissions. In this paper we will discuss the growing impact of the three areas of maritime port activities on climate change. A review of current and proposed environmental programs, established by government agencies, non-governmental organizations (NGOs), and private companies to promote awareness of the growing impact of global trade on climate change is discussed. Authorities at the ports of Aalborg, Denmark and Tangier Med Port, Morocco, are interviewed and data collected. It is concluded that although the ports are operating in different countries and cultures, management in both ports are aware of current environmental programs and the need for a focus on reduction of GHG emissions. A comparison of each port's specific activities to address climate change is presented. Results demonstrate that no matter the type of port, or where the port is located, enhancing and building stakeholder networks, including ship operators, port managers, and overland transport distributors, is needed to optimize efforts in reducing GHG emissions.

Introduction

According to the International Chamber of Shipping (ICS):

> "*the international shipping industry is responsible for the carriage of around 90% of world trade*" (ICS, 2018).

Furthermore,

> "*World seaborne trade reached 10.3 billion tons in 2016, after a steady increase over the last seven years. Since 2009, the volume of goods loaded and unloaded in ports worldwide has grown by 2.4 billion tons.*" (United Nations Conference on Trade and Development, UNCTAD, 2016).

With the world population currently at 7.3 billion and predicted to reach 9.7 billion by 2050 (United Nations Department of Economic and Social Affairs, UN DESA, 2016), transport by ships and the expansion of ports to load and unload cargo will continue to grow, especially in developing countries:

> *"With the highest rate of population growth, Africa is expected to account for more than half of the world's population between 2015 and 2050"* (UN DESA).

The United Nations International Maritime Organization (UN IMO) predicts a steady increase in GHG emissions from shipping with the potential of 250% by 2050 (Fig. 9.1).

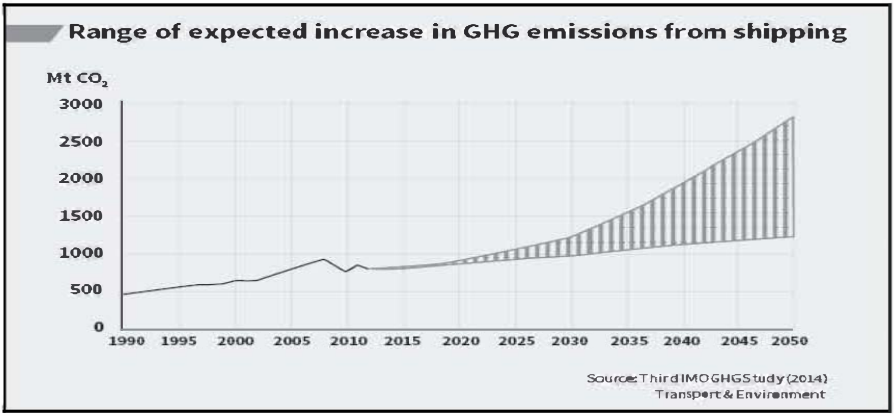

Fig. 9.1. Increase in GHG emissions from shipping, UN IMO, 2014

The UN IMO regulates shipping through flag states and port states. A flag state is where the ship is registered, and the port state is where the ship visits. Both have regulatory authority, but in port most port states have pollution regulations that ship operators are required to follow (Wright, 2013, UN IMO, 2018). Ports are regulated by national and state bodies, with ships in port being under the regulatory body of the port state (Fig. 9.2). Although state and flag port structure are too broad to accurately discuss in this paper, representatives of each group through the ship operators and port managers work together to coordinate and meet UN IMO and state regulatory requirements.

Fig. 9.2. Ships registered in a flag state loading and unloading in port state, Global Shipping, 2018

An excellent system between UN IMO flag states and port states in cooperating and understanding regulatory obligations has been established. Integrating the existing regulatory system, e.g., sea safety and port environmental standards, with goals and actions optimize the economic environment, while also integrating sustainable development initiatives.

Historically, port managers have better contributed to problem solving by establishing and communicating through internal and external stakeholder networks. These existing networks, however, are not solely focused on GHG emission reductions. Consequently, they may not be able to adequately respond to this important and sizable challenge, either by virtue of their membership's current expertise or, for example, by limited resources for time and money, competing projects, and rival priorities. Managerial and technical knowledge transfer among ports is, nevertheless, undoubtedly crucial in determining how to reduce GHG emissions from port operations (Fenton, 2015).

As we will discuss, ship transport emits the least amount of GHGs (ICS, 2018) (Fig. 9.3), but while in port, a significant amount of GHGs are emitted from ships waiting to dock or in a berth during loading and unloading (Winnes, et.al, 2015). The ICS also notes that the enormous scale of the industry means that shipping, nevertheless, is a significant contributor to the world's total GHGs, with continued growth as was shown in Fig. 9.1. Depending on economic and energy developments, shipping is predicted to increase 50% to 250% by 2050 (European Commission (EC), 2018, ICS, 2018).

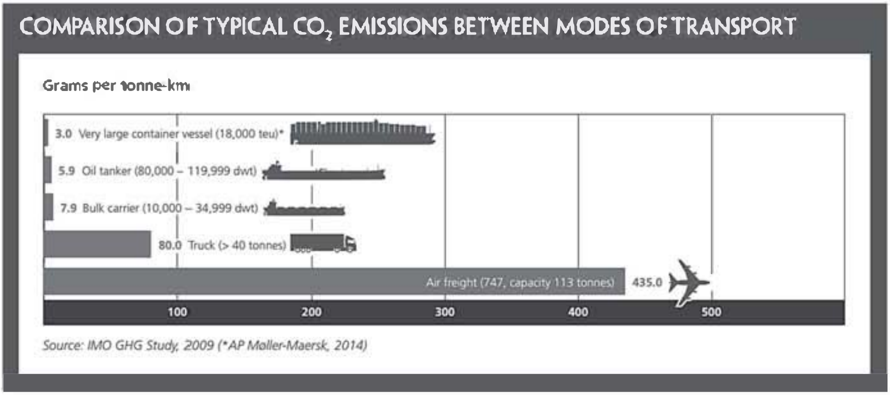

Fig. 9.3. "*Shipping is recognized as the most efficient form of commercial transport.*" (ICS, 2018)

The UN IMO, government agencies, private companies as well as NGOs understand that trade and shipping exports and imports are a major growth area. However, as will be discussed, the links of communication and networks that ensure trade goods are delivered and transported are not organized to the point to understand GHG reduction strategies. A study by the UN Organization for Economic Cooperative Development (OECD), points out that there is a lack of an international framework for addressing environmental impacts of international shipping (OECD, 2018).

To better understand how the connections can be better utilized between the shipping industry, port operations and supply chain transport, a case study is presented comparing the Port of Aalborg, Denmark, and Tangier Med Port, Morocco. The similarities and differences of the two ports are discussed, which include port size, location, and the goals and objectives for each port linked to GHG emission reduction from operations. The methods used by each port manager to address GHG emissions and energy use reduction are based on different strategies influenced by country culture, regulations, and economic development goals by each ports' governing body. The comparison of the two ports is the beginning of a larger study the authors envision will benefit the global shipping and port network in the increasing growth of global trade. Within this study, a discussion is focused on how each port assess the three areas identified by the OECD as contributors to a port's environmental impact (OECD, 1018):

- Problems caused by port activity itself;
- Problems caused by ships calling at the port; and

- Emissions from inter-modal transport networks serving the port.

Although the growth in shipping is discussed as it relates to port activities, this paper is focused on ships in port and the actions taken to reduce the in-port ship emissions. The comparative analysis completed on both ports in this paper will bring out not only how, and if, ports build networks of internal and external stakeholders with ship operators and truck or rail transport, but will also review the similarities of how port data is used to communicate between stakeholders.

Maritime ports and environmental impacts

There are currently 8,096 global maritime ports, which can be compared in various ways, including volume or value of trade, cruise passengers, revenues and storage capacity (American Association of Port Authorities, AAPA, 2018, Ports.com, 2018), (Table 9.1). Therefore, ships are in port daily loading and unloading cargo to distribute to growing populations of consumers.

Table 9.1. Global ports by continent, Ports.com, 2018

Global maritime ports	
North America	2,293
South America	253
Oceania*	373
Africa	421
Asia	1,719
Europe	3,024
Antarctica	13

*Australasia, Melanesia, Micronesia, and Polynesia

There are many types of ports, ranging from small to large, but as previously pointed out, due to population growth in all countries and increase in trade, all ports will continue to expand and be visited by an increasing number of ships. The most important cities in the world owe their origin and growth to their port location. Due to the storage demands, deeper waterways, larger terminal space for ship handling and warehousing, inlands roads and rail access has resulted in ports becoming larger than the cities they serve (Rodrigue, 2017).

A network of internal and external stakeholders is involved in port operation, from the ships arriving to load or unload, terminal operations in the loading and unloading, and product transport using trucks and rail (Fig. 9.4). In exchanging knowledge between port stakeholders, port managers can develop an integrated strategic plan that includes a stakeholder commitment to support reduction of environmental impacts contributing to climate change.

Fig. 9.4. Container ships make about 9000 and vehicle ships 1000 calls per week, World Shipping Council, 2018

A ship's major impact is the emission of carbon dioxide (CO_2) methane (CH_4) and dinitrogen oxide (N_2O). While in port waiting to load or unload a ship emits a significant amount in the port area. The most significant contributor to GHGs is prevalent in a port's operations:

- Ships waiting to dock;
- Ships in a berth;
- Port cranes, trucks, other equipment; and
- Trucks and rail in the transport of cargo to and from the port.

As will be discussed in the next section, there continues to be a lack of port stakeholder networks to focus on strategies to reduce overall stakeholder GHG emissions.

Infrastructure, location, and networks

As has been pointed out, the port state, port authorities, port tenants, and onshore transportation answer to national regulations (Paulsen, et al., 2018).

Therefore, the port infrastructure, location, and networks underline the actions taken by port managers on the issues addressing environmental impacts, including emissions. In identifying significant aspects (causes) of environmental change (effect), some port managers find the highest need in reducing water pollution and solid waste, but exclude energy reduction plans or programs to reduce CO_2 levels. This may be attributed to many factors, e.g., financial, port location, size, infrastructure, and regulating authorities.

However, as a collective, port operators that have established networks of stakeholders including ship operators and on ground transporters, increase the opportunities to learn about and include those GHG emissions that are significant when reviewed within a network. Networks such as transnational municipal networks (TMNs) have been established to provide opportunities for *"collective, participatory networks"*, which is crucial for ports in the fight against climate change (Fenton, 2015). Additional networks, such as EcoPorts, established by the European Port Sector in 1997 were integrated into the European Sea Ports Organisation (ESPO) in 2011. ESPO provides port managers with tools such as Self Diagnosis Method (SDM) checklists for risks, port comparison worksheets, and the ability to receive port expert advice and recommendations on environmental issues and port operations.

In building upon networks to exchange data on GHG emissions, port operators can demonstrate to stakeholders' methods used, categories selected, etc., to gather data to show emissions output. A 2013 GHG Inventory Report by the New York Port Authority provides an example of GHG emission sources (Fig. 9.5). Data shows that in 2013 the largest contribution to port authority GHG emissions is electricity consumption, which represents 71.5% of total emissions. The "other" category includes: refrigeration/fire suppression, landfill gas, emergency generators, fire pumps, and welding gases.

Exchange of data within the network and problem solving can provide stakeholders with a look at how each port is using, or planning to use, alternative energy sources such as biogenic fuels and methods to reduce fossil fuel use (Winnes, et al., 2015).

To better build stakeholder input, an emissions inventory is needed for port authorities to quantify the energy use and air quality impacts, of port operations (Fig. 9.6). An emissions tax is one method to increase revenue for port investment in alternative energy sources, such as the NOx tax in Norway (Maritime Cyprus Admin, 2018).

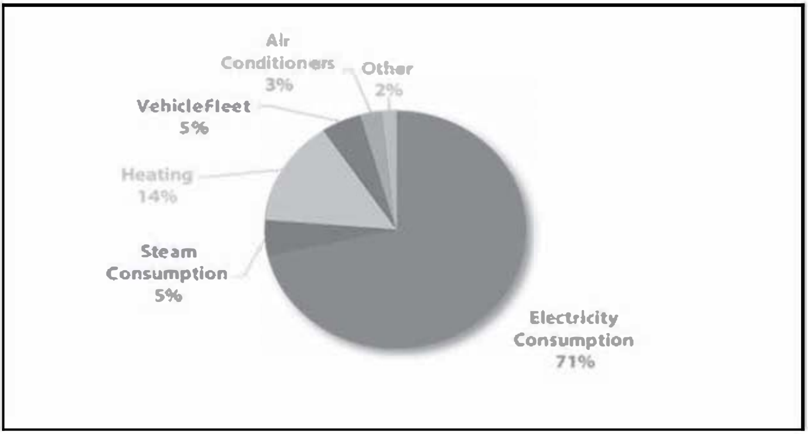

Fig. 9.5. GHG port emissions by source, New York and New Jersey Port Authority

Fig. 9.6. Trucks waiting to enter the Los Angeles port, Richard Simon, 2016

As pointed out by the United States (U.S.). Environmental Protection Agency (EPA): as a contributor of GHG emissions, port inventories would assist in assessing and developing emission reduction strategies (EPA, 2007). In future growth estimates from shipping as discussed in the paper's introduction, port managers, and relevant stakeholders should complete port inventories and establish baselines to track performance measures. Port managers with established relevant stakeholder connections ensure climate change and societal health issues are addressed. Not only are these issues recognized by port managers, suppliers, and city leaders, but in addition, key performance indicators are established to track emissions reduction.

In 2011, an EC white paper suggested that European Union (EU) maritime transport CO_2 emissions be cut by 50% of 2005 levels by 2050. However, at the time of the EC white paper, the EU did not track emissions from international shipping. Therefore, the EC white paper initiated a study that resulted in the EU establishing a strategy for integrating maritime emissions into EU emissions reporting data (EC, 2013, 2018).

The basis of successfully integrating climate change impacts is the foundation upon which managerial and technological methods are being built. This is a form of benchmarking. (Puig, et. al, 2015). In the next section, the development of management guides, tools, and incentives has been accelerated by government agencies and NGOs to assist port managers and shipping operators in better identifying and tracking activities that contribute to climate change. As ships increase the need for port space to deliver cargo, so is the increase of GHGs from ships in port berths waiting to unload cargo. A study of the Gothenburg port, Germany, in 2010 shows the highest release of CO_2 emissions by a ship in port berths at 53%, with 23% in the fairway channel, approaching the port (Winnes, et al., 2015).

Tools, guidance, and incentives

In 2007, the U.S. EPA published a guide for ports to assist in the implementation of an environmental management system (EMS) based on the ISO 14001 EMS standard.[4] This was one of the first management tools EPA published to assist ports in environmental impact assessment. The EPA promotes educational programs on air pollution and emissions reduction (EPA, 2018).

The U.S. Department of Transportation's Maritime Administration (MARAD) provides environmental management assistance to U.S. ports in reducing GHG emissions. The U.S. is also implementing programs that offer financial incentives for port managers to reduce emissions. (U.S. MARAD, 2018) (Fig. 9.7).

[4] For more information on related elements in EMSs, see chapter eight, *The Plan-Do-Check-Act Cycle to Mitigate Climate Change* in **Demystifying Climate Risk Volume II: Industry and Infrastructure Implications** by P. Barnes (LeBlanc, C. ed., Cambridge Scholars Publishing, 2017).

Fig. 9.7. U.S. Maritime Administration provides $4.8 million in port investment grants, 2018

In 2013, the EC joined other UN groups to create workshops to assist European port managers in better understanding port impacts on climate change (UN Economic Commission for Europe (UNECE), 2013, UNCTAD, 2017). Several organizations have been created or have added sectors focused on GHG from European ports, including the World Maritime University created by the UN's UN IMO. In 1983, the UN IMO introduced education programs and promoted regulations to assure safe, secure, and efficient shipping on clean oceans. The UN IMO continues to adopt regulations focused on reducing pollutants from ships and emissions of GHGs from international shipping (UN IMO, 2017).

> *"The EU is calling for a global approach to reducing greenhouse gas emissions from international shipping – a large and growing source of emissions. As a first step, large ships using EU ports will be from 2018 required to report their verified annual emissions and other relevant information"* (EC, 2018).

The UNCTAD secretariat completed a survey of ports in 2017 to assist in:

> "understanding weather and climate related impacts on ports and to identify data availability and information needs, as well as determine the current levels of resilience and preparedness among ports" (UNCTAD, 2017).

The survey not only assisted port management in understanding how they were being affected by climate change, but also provided the data to assist ports in better understanding the "implications for effective climate risk assessment and adaptation planning." (UNCTAD, 2017)

Additional country programs to reduce ship, port operations, and transport emissions include (Maritime Cyprus Administration, 2018):

- Panama Canal Authority program allows greener ships to have priority slots;
- Spain includes environmental incentives;
- Shanghai, China, has an emission-trading scheme; and
- Norway uses a NOx tax to put additional responsibility on shippers and port operators.

As continued global growth requires transport of cargo to the ports in the 222 countries listed by Port.com, port authorities will continue to strategically align port operations with global environmental impacts. In the next section a discussion of two ports includes a comparison of the similarities and differences of these ports in implementing sustainable development plans based on the UN Sustainable Development Goals (SDGs), including UN SDG 13 Climate Action. A focus of the two ports in this study is to review the priorities of both ports in reducing GHG emissions.

A case of two ports

In the following case study, each port is implementing and enhancing sustainable development plans. In developing the plans, each port understands how port activities contribute to detrimental environmental impacts, including energy use and GHGs. The ships at berth consume fuel and produce noise and vibrations generating different types of pollution to all the natural coastal elements: the water, the air, and the seabed (Borriello, 2013). Transport of cargo by trucks and rail increase the port's GHG emissions. In our comparison of the Tangier Med Port and The Port of Aalborg, Denmark, we will continually go back to how each port implements and maintains programs to reduce GHG emissions.

Methods

A description of Tangier Med Port, Morocco and The Port of Aalborg, Denmark is provided, which includes location, infrastructure, and port activity. Port authorities are interviewed and environmental impact data is collected. Similarities and differences in port environment impact data is listed and reviewed. Significant impacts are selected and objectives and targets for reducing emissions are discussed. Reviews of each port address the context, stakeholders, identifying activities and significant impacts to be tracked. Collected data is discussed and techniques used by each port assessed, including use of indicators selected, to monitor and measure performance.

Tangier Med Port Morocco

Tangier Med Port is a cargo port located about 40 km east of Tangier, Morocco (Fig. 9.8). It is the largest port in Africa and the third largest of the Mediterranean by capacity. The port went into service in July 2007. Its initial capacity is 3.5 million twenty-foot equivalent unit (TEU) shipping containers and will reach a capacity of 9.5 million TEUs[5]. The port is included as part of Morocco's economic policy orienting Morocco toward exports, based on eight clearly identified export sectors, with emphasis on free trade (Tangier Med Port, 2018).

Fig. 9.8. The maritime station of the Tangier-Med Port

Furthermore, Tangier Med Port is an important economic base in northern Morocco, in terms of jobs, creation of added value, and foreign

[5] The twenty-foot equivalent unit, or TEU, is an inexact unit of cargo capacity used to describe the capacity of container ships and container terminals.

investment. Its position on the Straits of Gibraltar, at the crossing of two major maritime routes, and 15 kilometers (km) from the EU enables it to serve a market of hundreds of millions of consumers through the industrial and commercial free zones which will be run by well-known private operators.

Tangier Med Port is part of a strong growth market of container transshipment and is striving to become the leading hub for cereal transshipment, a facility which is non-existent in the northwest African region at present. Tangier Med Port is coordinated and managed by the Tangier Mediterranean Special Authority (TMSA), a private company with public prerogatives, operating under an agreement with the state and interacting with the different ministries involved.

The Tangier Med Port sustainable development plan, which includes the use of ISO 14001:2015 EMS, has recently been implemented. Results and performance progress in meeting the two objectives for prevention of air pollution is evaluated during the EMS external audit in spring 2019.

The team at Tangier Med Port has identified two objectives for the prevention of air pollution:

1. Put in place a system for the management of addressing the parking of unaccompanied freight units (to avoid idle traffic). This objective is currently being tested by use of trailer trucks to minimize the maximum possible CO_2 emissions caused by trucks waiting to load and unload.
2. Put in place a measure of air quality to track the evolution of gaseous emissions (define the points of measurement). This objective is being met through reduction of CO_2 emissions and tracking gaseous emissions. The Tangier Med Port has contracted a laboratory to measure emissions from activities within the port area. Tracking of CO_2 and actions plans to reduce emissions is a requirement to meet the Port's certification to ISO 14001:2015.

A cost/benefit study is currently being conducted on implementing solar panels at the port as a continuing focus on alternative energy options.

Progress toward developing action plans for the two objectives is ongoing. Baselines will be established, and measure points identified. A solar energy plan is being integrated into Tangier's energy use program, including cost/benefit analysis, and best location for solar panels. The Tangier Med Port will continue to be part of this ongoing study in maritime port impact on climate change. As an emerging economy Tangier's growth in international trade will continue to grow as North Africa continues to develop.

The Port of Aalborg, Denmark

The Port of Aalborg is located outside the city on wide-open space. Included for expansion of the Port of Aalborg Terminal is 4.2 million square meters in the hinterland, where the infrastructure is closely linked to a major highway (Fig. 9.9). Approximately 100 companies have established facilities within this new industrial park, of which about half of the area is situated near wharfs. The Port of Aalborg is a rational and active hub for all types of freight and all kinds of transport by ship, truck and rail – with Nordic Transport Centre, integrated into the overall service, which also includes Danish Carriers terminal and warehouse. As of March 2017, the Port of Aalborg became the first CO_2-neutral port in Denmark, one of the few CO_2-neutral ports in the world.[6]

Fig. 9.9. Port of Aalborg, Denmark

Together with Aalborg Portland A/S, the Port of Aalborg is the fifth largest port system in terms of total cargo volume in Denmark. The Port of Aalborg is also Europe's only base-port for Greenland and a global container network through feeder route Rotterdam–Aalborg–Gothenburg. The

[6] https://aalborghavn.dk/news-(1)/port-of-aalborg-is-the-first-co2-neutral-port-in-d.aspx.

container terminal at the Port of Aalborg has a capacity to handle 100,000 containers annually.

Aalborg port managers have committed to reducing GHG emissions. To reduce emissions, the port built a solar power plant in 2014, which annually produces approximately 80,000 kilowatt hours (kWh) for port operations. Aalborg converts energy consumption into equivalent CO_2 emissions to better understand where the largest output of emissions is based and focus on reduction of energy use (Fig. 9.10). The generation of the solar and wind turbines go back in the electrical grid with no emission conversion. The drop of CO_2 balance in 2016 is due to line solar panels and the increase of CO_2 in 2017 due to the new coal terminal and the operation of cranes, transport, and handling machines.

Despite this internal progress, the Aalborg port does not currently seek GHG information from ships. Consequently, the port needs to expand its networking capabilities to work together with external stakeholders in further decreasing GHG emissions.

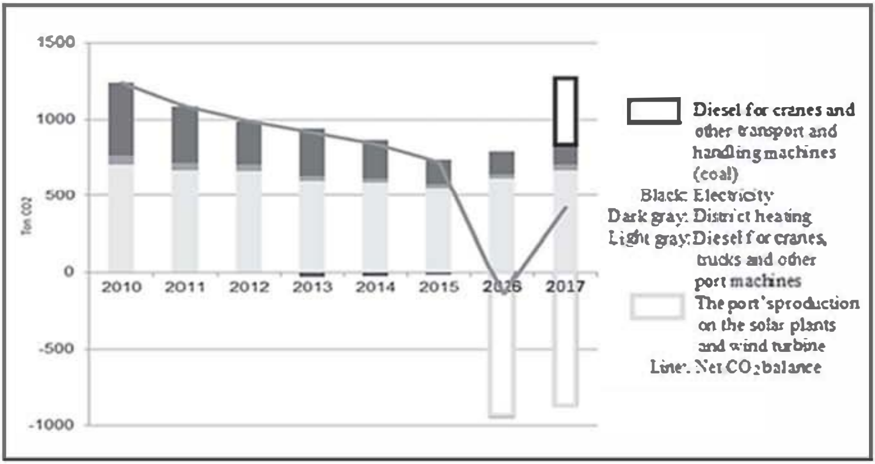

Fig. 9.10. Aalborg tracks energy consumption converted into equivalent CO_2 emissions

Comparative analysis

Each port identified environmental impact areas where initiatives have been implemented to reduce environmental impact. Port management was interviewed and discussion of each port's decision to address energy use and CO_2 reduction was listed. As described in Table 9.2, each port created objectives to focus on renewable energy sources, and reduction or modification of activities with CO_2 emissions. The similarities and differences of the ports and the methods used in each port to reduce GHG emissions, is listed as part of environmental impacts. The comparison of port emission reduction programs will continue to be tracked to assess performance progress. We will also review the scope of each port's environmental assessment in comparison to the recommended categories by the OECD for a port to collect data to encompass a complete assessment of energy use and emission output, port activities, ship activities, and transport activities.

Table 9.2. Significant similarities and differences between two ports in reducing climate change impacts

SIMILARITIES		
	Principle	**Activities**
Tangier Med	Waste reduction	Solid and liquid waste management
	Environment/habitat protection	Establish and execute biodiversity plan
	CO_2 emissions reduction	Implement solar energy plan
Aalborg	Waste reduction	Solid and liquid waste management
	Environment/habitat protection	Establish and execute biodiversity plan
	CO_2 emissions reduction	Create solar panel units and install wind turbines

Table 9.2. Significant similarities and differences between two ports in reducing climate change impacts (cont.)

DIFFERENCES		
	Principle	**Activities**
Tangier Med	Air pollution reduction	Reduce port truck idle time
	Waste reduction	Reduce paper consumption
	Toxins reduction	Mitigate dangerous materials
	Gaseous emissions reduction	Create points to measure
	EMS	Authenticate identification and listing of aspects to achieve ISO 14001 2015 EMS certification
Aalborg	Fossil fuel use reduction	Use electric cars, natural-gas fueled trucks, and electric cranes
	Review ship Environmental Performance Index	Take appropriate action(s) in response
	Initiate facility infrastructure and security procedures	Implement bunkering of liquified natural gas (LNG)
	Determination of best management practices	Promote practices such as bicycling to reduce vehicle emissions and foster social activities
	Raise environmental awareness	Produce monthly press release
	Industrial ecology application	Re-use waste heat for building heat

Both Morocco and Denmark place great importance on environmental protection measures of port pollution as evidenced by solid and liquid waste management and the completion of biodiversity plans.

Despite these similarities, each port has a unique pollution prevention approach. Tangier Med has championed the prevention of air pollution, the reduction of paper consumption, and the mitigation of dangerous materials. The port of Aalborg would likewise benefit from these measures.

The port of Aalborg has put energy saving plans in place that will reduce CO_2 emissions, including an increase in the use of renewable energies and a decrease in the use of fossil fuels (electric cars, natural-gas fueled trucks, and electric cranes). An assessment of selling waste heat from cooling facilities to the district heating network is an excellent example of symbiosis[7] within the Aalborg community. A program introduced by Aalborg management entails differentiated port changes following review of the ship's Environmental Performance Index. An additional program is the creation of a facility (infrastructure and security procedures) for the bunkering[8] of liquified natural gas (LNG) from truck to vessel. This would also be an excellent objective for the Tangier Med Port.

In Morocco, two objectives that focused on air pollution and GHG were listed and discussed. A solar energy plan was established to review the benefits of constructing a solar panel facility. At the Tangier Med Port a focus on using an EMS authentication emphasizes identifying and listing of environmental aspects to achieve the ISO 14001, 2015 EMS certification.

The port of Aalborg, on the other hand, is not as committed to the EMS authentication standard; instead, they give more attention to the coordination of a combination of advanced ideas and best management practices such as improving the conditions for cyclists between the port, the industry area and the city, which also includes the construction of a new bicycle shed at the port, and renting an electric bicycle for personnel use in the summer. These programs not only reduce vehicle emissions but promote social activities for employees.

Aalborg also strives to raise awareness of sustainability in local industry and promote cooperation and innovation with a monthly press release, among other initiatives, and to accelerate the development of a local industry 'cluster' for circular economy initiatives, including material recycling.

Results

This study demonstrates that two ports in different countries have similar objectives in reducing their environmental impacts. The major difference in each port's actions on sustainability efforts such as alternative energy use is due to the port's established longevity in the community. Tangier Med Port is new and located further from the city center and a community population. Aalborg port is an established port that has grown with the city. There is an excellent opportunity for management at Tangier Med Port to coordinate with the Aalborg Port in implementing sustainability objectives in alternative energy such as wind turbines.

[7] In industrial ecology, symbiosis refers to an interaction among different entities in a community meant to benefit all.

[8] Bunkering is the process of transferring LNG to a ship for use as fuel. It is a less polluting methods of fueling compared to marine gas oil and heavy fuel oil.

Through this comparative analysis, two significant environmental impacts regarding fossil fuel use and energy consumption could be potential areas that managers at the Tangier Med Port could target based on continual improvement within the port's sustainable development plan. In comparison to the port of Aalborg's best practices in reducing fossil fuel use and energy consumption, the Tangier Med Port could use its ISO 14001 EMS in recognizing fossil fuel use and energy consumption as two areas that would be significant aspects within the EMS framework. In reviewing their operations, Tangier managers could identify those activities with significant energy consumption and put into place an action plan to reduce energy consumption using fossil fuels.

Discussion and recommendations

Two areas were identified by this study that has been recommended for the Tangier Med Port management to benchmark: (1) reduction of fossil fuel consumption, and (2) energy savings and CO_2 reduction. In targeting these two areas of energy use and emissions, the Tangier Med Port will build upon its energy and environmental management system continual improvement cycle.

The port of Aalborg pays special attention to energy savings and thus CO_2 reduction. The port has 2-megawatt (MW) wind turbine and solar panels, from which the electricity production is transferred directly to the grid. The electricity production is included in the port carbon account. However, the port of Aalborg does not track ship or land transport (idle trucks or rail) emissions through a stakeholder network.

Both ports have an opportunity to engage in stakeholder network development. Although each port is aware and is using environmental programs established by international organizations to reduce environmental impacts, ship operators and truck and rail stakeholders could be included in a productive GHG emissions reduction program.

A stakeholder network and communications channel will establish a partnership that can focus on energy reduction, continued growth of alternative energy methods, and develop action plans and methods to track GHG emissions within the shipping and transport areas. The stakeholder objective would be in line with the European Union's 2018 decree that ships report all GHG emissions at all ports of call. The study also found that the state port and the UN IMO flag port connection should be further developed. There are communication channels that ensure ship safety and other requirements regulated by the UN IMO are coordinated with port operations. Nevertheless, this report has determined that more emphasis should be placed on GHG emissions, and environmental impacts overall, in future strategic planning. The state and flag port connections are included in the recommended internal and external stakeholder network.

The stakeholder network will also be a first step in meeting the OECD three categories needed for ports to make a significant contribution to the reduction of GHG emissions, as reported under the tools, guidance, and incentives section of this paper.

Conclusion

Ship transport emits the least amount of GHGs, but when in port the amount of GHG emissions increase due to port operation from cranes, trucks, and other equipment using fossil fuel. In addition, the emissions of trucks and rails to transport goods to customers continue to increase the GHG effect on global warming. This combination of sources that contribute to the causes of climate change is becoming a top priority of the UN, country regulating bodies, private organizations, and NGOs as they realize the continued growth of global trade.

In this paper, we have discussed programs designed to assist the shipping industry, port authorities, and transport supply chains in identifying and implementing strategies to reduce climate change impacts as well as the lack of an international framework for stakeholder networks. The case study of the two ports provided a look at how port internal and external stakeholder networks can be established to better coordinate programs across global shipping partnerships. Through a review of these ports, we conclude that despite the similarities of their methods in managing environmental protection, the port of Aalborg and the Tangier Med port have unique and specialized approaches to reducing emissions contributing to climate change. It is recommended that the Tangier Med Port increase its attention on reduction of fossil fuel consumption, energy use, and CO_2 emissions. The port of Aalborg continues to implement its CO_2 reduction plans, but should build upon internal and external stakeholder coordination.

The study of these two ports is ongoing by the authors, which include contacts within each identified port network. Continued research into programs such as the new EU 2018 emissions requirement in shipping, as well as established partnerships in the Mediterranean, is ongoing. Finally, continued research in this area will provide better understanding of how the connections between the flag state and the port state can be better coordinated to enhance GHG data collection within the shipping, port operations, and transport supply chains. The authors conclude that the complex global maritime trade industry and its impact on climate change will continue to be a growing area of research.

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CHAPTER TEN

CLIMATE RISK MANAGEMENT: IMPLEMENTATION ASPECTS

ISAMU 'SAM' HIGUCHI[1]

Abstract

Implementation aspects to climate risk management require a mutually acceptable climate database and mutually acceptable climate information sources. These are the initial components needed for understanding and collaboration that will lead to actionable-knowledge. These components are all part of a program logic model leading to implementation actions. Additionally, publications from boundary organizations[2] can be helpful in deepening the knowledge needed for decision making and implementation actions; a publication by Ouranos is one cited example. Moreover, a flowchart to United States (U.S.) and international reference sources of climate data and information are provided to aid in the analysis needed for implementation; an appendix cites specific URLs to access the reference sources. Finally, a discussion ensues concerning custom scenario analysis. The custom analysis remarks include: (1) dimensional framework,

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[1] Sam Higuchi is an engineer at the National Aeronautics and Space Administration (NASA) headquarters in Washington, DC, with service in the public sector since the 1980s. He has a law degree from the University of Iowa and graduate degrees in public administration and science from the American University and the University of Minnesota, respectively. Among his accolades are the Bronze Medal Award from the National Oceanic and Atmospheric Administration (NOAA), Environmental Engineer of the Year Honor Award Winner from the Conference of Federal Environmental Engineers, Partners in Quality Contracting Award from the Council for Excellence in Government, and Antarctic Service Medal from the U.S. Navy.

[2] As classically defined, boundary organizations facilitate collaboration and information flow. In environmental management, these organizations can also promote mutual understanding among stakeholders.

(2) selecting climate scenarios, and (3) temporal aspects of timescale and time horizons. This paper provides helpful and practical remarks and hints for climate-related risk management leading to implementation actions.

Background

At the 2nd International Technical Workshop on Climate Risk in 2017, the subject matter of this paper was presented in a training course using modules from a manual that has since undergone updates and revisions. This paper remains faithful to the core message presented at the workshop, while using a more appropriate approach following the re-sequencing of the topics covered.

Usable climate science is a challenge because providers of climate science are in many cases not the end-users, that is, consumers. The motto "build it and they will come" is troubling to many potential consumers trying to apply the "climate science products" by "climate science providers". Perhaps a better approach would be if climate science providers shifted from "output of products" to "consumer-customer service outcomes". The challenge of usable climate science has been discussed and remains a current challenge.[1]

Program logic model approach

The objective of this paper is to start using and applying currently available climate science. The first stage of this effort is to establish a program logic model for usable climate science. Actionable-usable climate science depends on two dimensions: (1) understanding and (2) collaboration. The progressive steps within the two dimensions of the logic model are: (a) data, (b) information, (c) knowledge, and (d) action.[2] Fig. 10.1 illustrates how the two dimensions are related to the progressive four steps. In order to have actionable-usable climate science, we need to have a basic mutual "understanding" of the subject matter for communication. Further, if we want "collaboration" we need to agree on a common source of "data" and "information" to get to the goal of "actionable-knowledge". The program logic model presents all the necessary elements to reach that goal.

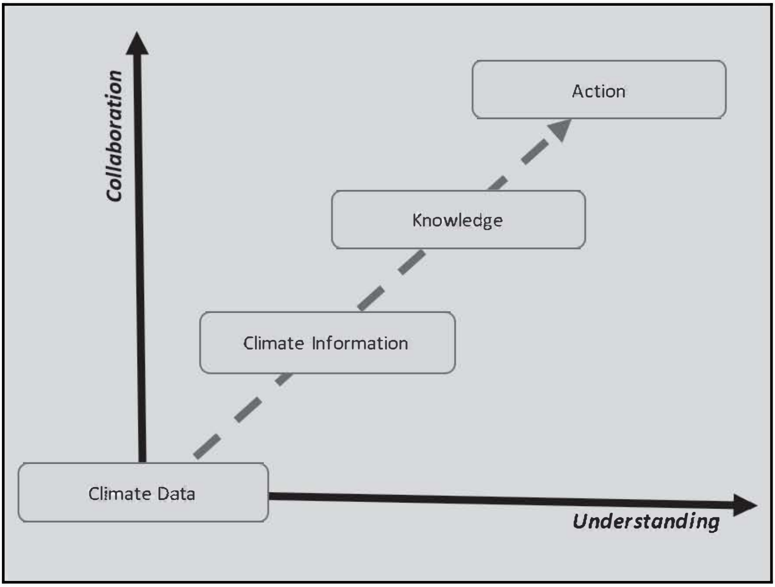

Image modified from Statistics, Knowledge and Policy 2007: Measuring and Fostering the Progress of Societies, OECD (2008), Ch34 p486, Fig. 34.3: The Transformation of Data to Information and Knowledge

Fig. 10.1. Program logic model: Transforming climate data into climate information, knowledge, and action

Pragmatically, the first challenge is to identify (1) a credible source of climate data and (2) a credible climate database that are mutually acceptable. Within the continental U.S., one climate database that is established as mutually acceptable for "technical managers" for the management of large public works programs and projects is *Downscaled CMIP3*[3] *and CMIP5 Climate and Hydrology Projections*[3] (U.S. Army Corps of Engineers, Bureau of Reclamation). Internationally, the Intergovernmental Panel on Climate Change (IPCC) has established the CMIP5 data in *KNMI*[4] *Climate Explorer* at *Climate Change Atlas* as an authoritative climate database.[4]

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[3] CMIP, or Coupled Model Intercomparison Project, provides a community-based infrastructure in support of climate model diagnosis, validation, documentation, and data access. The framework enables multi-scientific analyses and model improvements.
[4] Koninklijk Nederlands Meteorologisch Instituut or the Royal Netherlands Meteorological Institute.

These two climate databases serve as a starting point towards actionable knowledge.

The second challenge is to identify a credible source of climate information that is mutually acceptable. Within the U.S., one such source is the U.S. Globe Change Research Program's *National Climate Assessment*.[5] Internationally, a widely acceptable source of climate information are the IPCC's assessment reports.[6] For the non-climate scientist, these two authoritative sources of climate information offer the greatest credibility and serve as the second step towards actionable knowledge. As a foundation for understanding and communication, we have common sources of climate data and climate information. Using this foundation, we have the beginnings of actionable-knowledge for collaborative actions.

To be more successful in our collaborative actions, we need to deepen our "knowledge"; this is the third challenge. The third challenge is more difficult to resolve, likened to the search for a catalyst. For the non-climate scientist, one of the best practical sources is the 2016 publication, *A Guidebook on Climate Science Scenarios: Using Climate Information to Guide Adaptation Research and Decisions*[7] by Ouranos, a Canadian "boundary organization", bridging the gap between science providers and science users. It is a readable guide to aid consumers in obtaining a deeper knowledge about climate science for designing management studies and using climate science for decision making. The Ouranous document is a free, downloadable guidebook. Other publications[8] also provide a deeper knowledge of climate science, but they are more difficult to read.

User's perspective: Flowchart to sources of climate data and information

Australia has published an excellent document that provides the deeper knowledge needed by consumers of climate science. The Australian publication can only serve as a "format" for what might be helpful for North America because the Southern Hemisphere has different atmospheric weather and climate patterns. The Australian "format" is outstanding because it is based on a flowchart of data and references to answer a sequence of five basic questions. The basic questions are:

- "I want to learn about how climate change may affect my region, where do I find the information?";
- "I'd like to know more about climate change science, where do I find the information?";

- “I need some summary information for my report, where do I get it?”;
- “I want to explore maps related to climate change, where do I find maps?”; and
- “I need climate data, where do I find data?”.

Component parts of the five questions are illustrated in Fig. 10.2. The author of the technical paper has taken this flowchart pattern and created a U.S. flowchart prototype that lists URLs[5] for climate data and climate information. This U.S. flowchart prototype with URLs is provided in the Appendix.

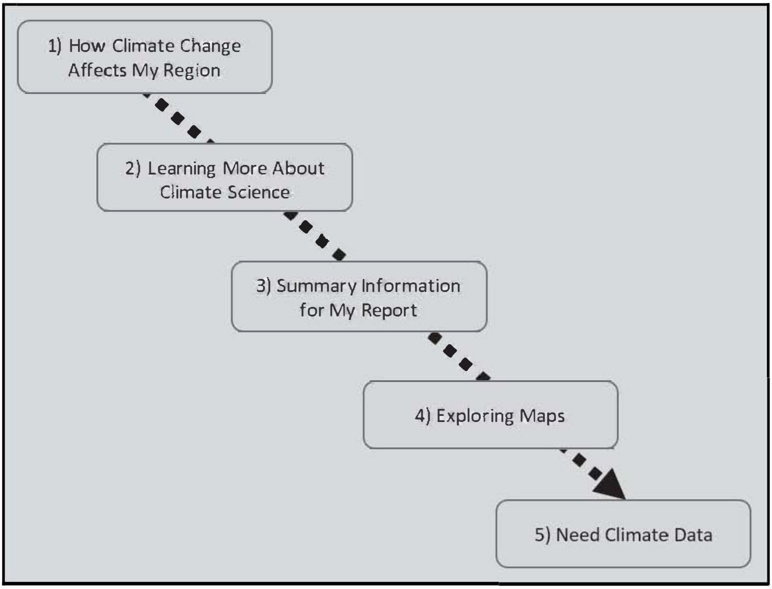

Fig. 10.2. Flowchart to climate data and climate information

Doing your own custom scenario analysis

Moving beyond appraising sources of climate data and information is performing the actual climate scenario analysis. This custom analysis requires an understand of some fundamental elements. These elements

[5] Acronym for Uniform Resource Locators, or website addresses.

include: (1) dimensional framework, (2) selecting climate scenarios, and (3) temporal aspects – timescale. These elements are presented in a detailed step-by-step sequence below.

Custom analysis, step 1: Dimensional framework

The goal of step 1 is to understand that the dimensional framework is a three dimensional "cartesian coordinate system". The "x-axis" and "y-axis" make up the geospatial "plane", and the "z-axis" is the temporal dimension; as illustrated in Fig. 10.3. Within the geospatial plane are the sites of specific organizational importance such as the locations of assets and capabilities and, more specifically, sites of: (1) core operations, (2) value chain significance, and (3) boarder network significance. Additionally, the geospatial plane has climate data and information mapped on it.

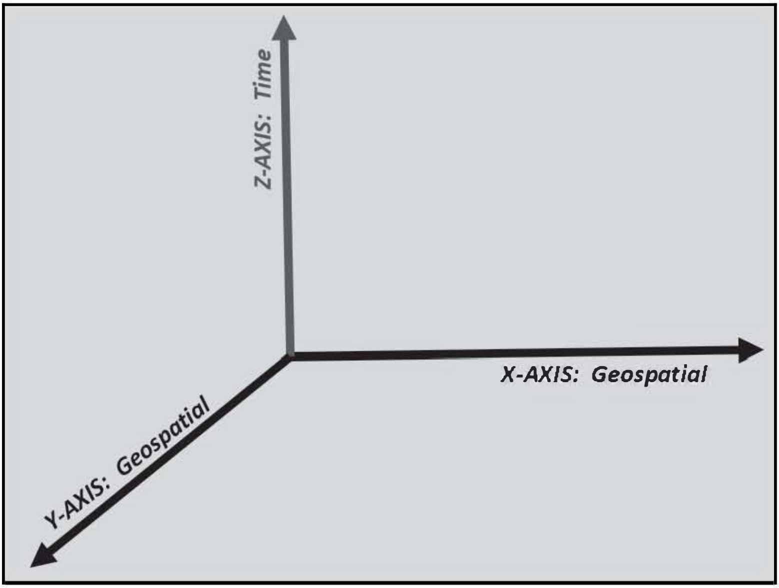

Fig. 10.3. Dimensional framework: Geospatial and temporal (time) dimensions

The temporal dimension incorporates changes in climate over time. Typically, the time range of the analysis is from approximately 10 years to the end of the century. The time range is usually divided into incremental sub-unit time periods referred to as "time-slices" by climate scientists. No set methodology-practice or set standard exists for the duration of these "time-slice" periods, and their duration can vary depending on the purpose of the analysis and/or the preferences of the analyst. Additional details concerning temporal aspects are provided in step 3.

Custom analysis, step 2: Selecting climate scenarios

The range of commonly accepted climate scenarios under CMIP5 currently includes four climate scenarios: (1) CMIP5–RCP[6] 8.5 (high greenhouse gas or GHG emissions), (2) CMIP5–RCP 6.0, (3) CMIP5–RCP 4.5, and (4) CMIP5–RCP 2.6. According to the *Climate Science Special Report*, the actual GHG emissions trend for the past 10 years follows the projections for CMIP5– RCP8.5.[10] Further, CMIP5–RCP 2.6 is no longer thought to be an achievable pathway climate scenario, and is only used as an historical reference for extremely aggressive GHG emissions mitigation initiatives. Finally, CMIP5–RCP 4.5 is an achievable pathway and is consistent with the Paris Agreement.[11]

Several groups have settled on CMIP5–RCP8.5 and CMIP5–RCP 4.5 as a best practice for custom scenario analysis. One important group, the U.S. Global Change Research Program has taken the position from the Fourth National Climate Assessment (NCA4) that these are the preferred climate scenarios for analysis.[12] The Task Force on Climate-related Financial Disclosure (TCFD) also prefers to use these two scenarios in its method for doing "scenario analysis". The Rand Corporation, an organization recognized for doing quality management studies, has likewise used these two scenarios.[13] Additionally, the Rhodium Group, commissioned to do a study for the Risky Business Project (financed by Bloomberg Philanthropies), also employed these scenarios.[14] One can only conclude that using these two scenarios is presently a good practice in conducting custom scenario analysis. Fig. 10.4 illustrates CMIP5–RCP8.5 and CMIP5–RCP 4.5 scenarios.

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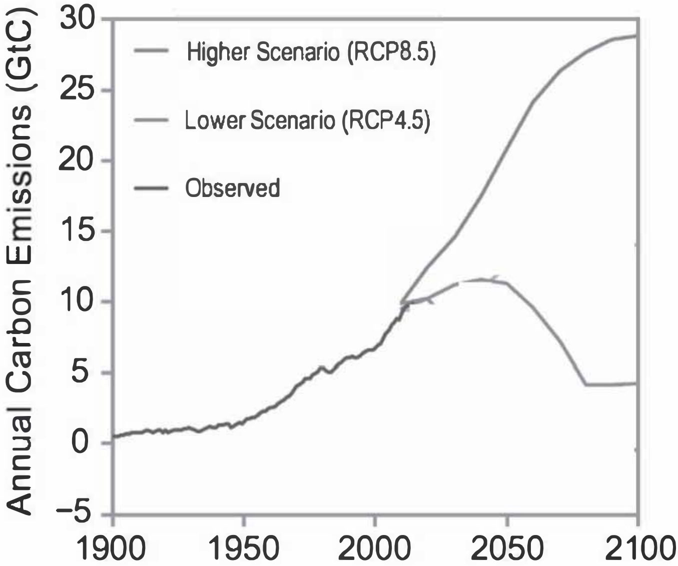
[6] Representative Concentration Pathways. For more information, see chapter three "*A '4th Wave' Perspective on Climate Risk Management*" and chapter four, "*Adjusting Precipitation Intensity-Duration-Frequency (IDF) Curves in Engineering Design*".



GtC (above) = Gigatonnes carbon
Image modified from the *Fourth National Climate Assessment, Volume 1: Climate Science Special Report*, p16, Fig. ES 3.

Fig. 10.4. Climate scenarios: CMIP5–RCP 8.5 and CMIP5–RCP4.5

Custom analysis, step 3: Temporal aspects – timescales and time horizons

Issues related to "time", like timescale and time horizons, are important to pragmatic considerations of a custom scenario analysis. Resources like labor, time, and money from a business-management perspective are always in limited supply. It is not practical to use an infinite set of climate scenarios and timeframes; every different climate scenario and different timeframe costs additional money. So, it is prudent to design the custom scenario analysis that incorporates the screening approach using as small a finite set of climate scenarios and timeframes as possible.

One prudent approach is to use a method based on a sequence of questions, and many climate scientists have begun to do so. This has relevance to business managers doing a custom scenario analysis. The sequence of questions is as follows:

- "How bad could it get?";
- "How soon could it happen?"; and
- "Does climate mitigation, like the Paris Agreement, improve my situation?".

Pragmatically, "how bad could it get", is taken to mean climate scenario CMIP5–RCP8.5 (high emission) at the end of the century (2100). Given this endpoint, the business-management analysis question is: "Can my business survive under this extreme situation?" Business survival includes assets, capabilities, and resources. If the answer to this business question is "Yes", no further analysis is needed. If the answer is "No", then further analysis is necessary.

Further analysis means answering the next two questions listed above. So, the next analysis question that needs to be answered is: "How soon could it happen?" Again, the climate scenario used is CMIP5–RCP8.5, but several intermediate time points, relative to the end of the century, are used. As previously stated, there is no standard for choosing these intermediate timeframes. However, at least two timeframes have been suggested: (1) 10 to 30 years and (2) greater than 30 years to the end of the century. The business question asked under these circumstances is: "Can my business survive under these intermediate timeframe situations?"

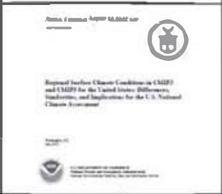
The third analysis question can be stated as: "Does a different potential climate scenario pathway that incorporates GHG mitigation provide a better future at the end of the century?" The Paris Agreement is concerned with implementing GHG mitigation for a healthier atmosphere at the end of the century. The treaty aligns with climate scenario CMIP5–RCP4.5. Essentially, the business questions are: (1) "Does my business benefit from the Paris Agreement climate scenario?" and, finally, (2) "*If my business benefits from the Paris Agreement climate scenario, what climate mitigation actions to reduce GHG emissions should my business be implementing?*"

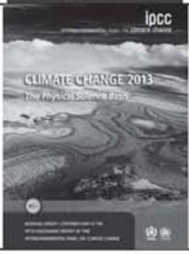
Concluding remarks

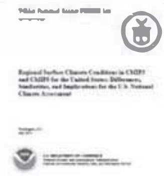
Custom climate scenario analysis has many advocates,[15] including the TCFD. Furthermore, the TCFD has published a technical supplement devoted to the use of scenario analysis.[16] This is likely the beginning of a trend in business management to conduct custom climate scenario analyses as part of climate-related risk management.

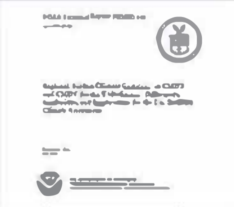
Appendix

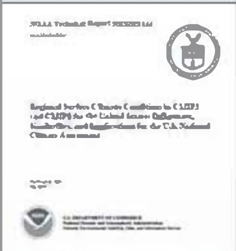
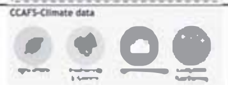
U.S. flowchart of climate data and information (as of 4 May 2018)

1) LEARNING HOW CLIMATE MAY AFFECT MY REGION			
		TITLE and URL	REMARKS
U.S.		4th National Climate Assessment (NCA4), Volume 2: "Climate Change Impacts and Adaptation", (pending – December 2018) URL: https://www.globalchange.gov/content/nca4-planning	
U.S.		National Oceanic and Atmospheric Administration (NOAA)-NESDIS Technical Report 144: "Regional surface climate conditions in CMIP3 and CMIP5 for the U.S.: Differences, similarities, and implications for the U.S. National Climate Assessment" URL: https://repository.library.noaa.gov/view/noaa/1303	*See CMIP5, RCP 8.5*
U.S.		U.S. Army Corps of Engineers (ACE): "Recent U.S. Climate Change and Hydrology Literature Applicable to USACE Missions" URL: http://www.corpsclimate.us/rccciareport.cfm	*USACE regions*
Global		Intergovernmental Panel on Climate Change (IPCC) AR5—Part B-Regional Aspects URL: https://www.ipcc.ch/report/ar5/wg2/	
Global		IPCC: "Annex I: Atlas of Global and Regional Climate Projections Supplementary Material RCP8.5" URL: https://www.ipcc.ch/pdf/assessment-report/ar5/wg1/supplementary/WG1AR5_AISM8.5_FINAL.pdf	
Global		KNMI Climate Explorer–Climate Atlas URL: https://climexp.knmi.nl/plot_atlas_form.py	*12-km resolution*
Global		Meteorological (Met) Office: "Climate: Observations, projections and impacts... [for various countries]" URL: https://web.archive.org/web/20160804023834/http://www.metoffice.gov.uk/climate-guide/science/uk/obs-projections-impacts	
Global		Met Office: "Climate: Observations, projections and impacts SUMMARY FACTSHEET... [for various countries]" URL: https://web.archive.org/web/20161021222429/http://www.metoffice.gov.uk:80/climate-guide/science/uk/expert-advice/COP/COP18	

2) LEARNING ABOUT CLIMATE SCIENCE			
		TITLE and URL	REMARKS
U.S.		4th National Climate Assessment (NCA4), Volume 1: Climate ScienceSpecial Report URL: https://science2017.globalchange.gov/	
Global		IPCC 5th Assessment Report (AR5) The Physical Science Basis URL: https://www.ipcc.ch/report/ar5/wg1/	

3) INFORMATION FOR A REPORT			
		TITLE and URL	REMARKS
U.S.		4th National Climate Assessment (NCA4), Volume 1: Climate Science Special Report URL: https://science2017.globalchange.gov/	
U.S.		4th National Climate Assessment (NCA4), Volume 2: "Climate Change Impacts and Adaptation", (pending–December 2018) URL: https://www.globalchange.gov/content/nca4-planning	
U.S.		NOAA-NESDIS Technical Report 144: "Regional surface climate conditions in CMIP3 and CMIP5 for the U.S.: differences, similarities, and implications for the U.S. National Climate Assessment" URL: https://repository.library.noaa.gov/view/noaa/1303	*See CMIP5, RCP 8.5*
U.S.		U.S. Army Corps of Engineers (ACE): "Recent U.S. Climate Change and Hydrology Literature Applicable to US Army Corps of Engineers Missions" URL: http://www.corpsclimate.us/ ccaciareport.cfm	*USACE regions*
Global		IPCC 5th Assessment Report (AR5) Synthesis Report URL: https://www.ipcc.ch/report/ar5/syr/	
Global		IPCC 5th Assessment Report (AR5) The Physical Science Basis URL: https://www.ipcc.ch/report/ar5/wg1/	
Global		IPCC 5th Assessment Report (AR5) Impacts, Adaptation and Vulnerability URL: https://www.ipcc.ch/report/ar5/wg2/	

4) EXPLORE MAPS			
		TITLE and URL	**REMARKS**
U.S.		NOAA–NESDIS Technical Report 144: "Regional surface climate conditions in CMIP3 and CMIPS for the U.S.: Differences, similarities, and implications for the U.S. National Climate Assessment" URL: https://repository.library.noaa.gov/view/noaa/1303	*See CMIP5, RCP8.5*
Global		IPCC: "Annex I: Atlas of Global and Regional Climate Projections Supplementary Material RCP8.5" URL: https://www.ipcc.ch/pdf/assessment-report/ar5/wg1/supplementary/WG1AR5_AISM8.5_FINAL.pdf	
Global		KNMI Climate Explorer–Climate Atlas URL: https://climexp.knmi.nl/plot_atlas_form.py	*12-km resolution*

5) CLIMATE DATA			
		TITLE and URL	**REMARKS**
U.S.		NOAA-NESDIS Technical Report 144: "Regional surface climate conditions in CMIP3 and CMIP5 for the U.S.: Differences, similarities, and implications for the U.S. National Climate Assessment" URL: https://repository.library.noaa.gov/view/noaa/1303	*See CMIP5, RCP8.5*
U.S.		Downscaled CMIP3 and CMIP5 Climate and Hydrology Projections URL: https://gdo-dcp.ucllnl.org/downscaled_cmip_projections/dcpInterface.html	*See CMIP5, RCP 8.5*
Global		KNMI Climate Explorer–Climate Atlas URL: https://climexp.knmi.nl/plot_atlas_form.py	*12-km resolution*
Global		International Centre for Tropical Agriculture (CIAT) and The CGIAR Research Program on Climate Change, Agriculture and Food Security (CCAFS): GCM Downscaled Data Portal URL: http://ccafs-climate.org/	*Agriculture, biodiversity, ecology*

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11. Technical Supplement: The Use of Scenario Analysis in Disclosure of Climate-related Risks and Opportunities, Task Force on Climate-related Financial Disclosure (2017); page 25, Box A3.
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CHAPTER ELEVEN

IS SERIOUS CLIMATE ACTION SOONER THAN LATER A GOOD ECONOMIC BET?

CHRISTOPHER JUNIPER[1]

Abstract

Is it likely to cost humanity more, or less, to address climate change today instead of tomorrow? The many sincere attempts to estimate the answers with economic tools fail to become determinant because of too many variables and uncertainties. However, the preponderance of evidence backs taking a "conservative" approach and addressing climate change aggressively since that will minimize risks, and if done well the actions will enhance both economic health and national/global security.[2]

> "An ounce of prevention is worth a pound of cure"
>
> Benjamin Franklin, 1700s

> "The choice we face today is not whether or how to act, but how quickly we will do so."
>
> Global Commission on Climate and Economy

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[1] Christopher Juniper has been an environmental activist, educator, sustainability consultant and economic development professional for 40+ years. A charter member of the International Society of Sustainability Professionals, he was the primary author of its Associate-level certification study guide in 2016. His other accomplishments include: serving as sustainability and transportation planner for the nationally-award-winning sustainability program at U.S. Army Garrison Fort Carson, Colorado from 2003-2011; and overseeing the adoption of 'sustainable development' goals by Portland, Oregon in 1994 as the city's Economic Development Policy Manager. He has also worked with Rocky Mountain Institute and Natural Capitalism Solutions. He presently provides consulting through SustainALogic (www.SustainALogic.com) and serves on the boards of the Advanced Transit Association (ATRA) and Action Research Plus Foundation.

[2] All cost figures are in U.S. dollars shown by "$" unless otherwise noted.

Introduction

Will the benefits of serious action to address climate change sooner than later exceed the costs for humanity? It is a simple question with very complex answers. It is akin to risky investment decisions for enterprises or individuals, such as a family decision to stretch and buy what seems like an expensive home, when the evidence is that home prices are likely to increase faster than family income in coming years. The numbers that can be assembled to guide the decision are not determinant, especially if you try to project the resale value, and the ownership costs a century into the future.

This chapter will explore both economic cost/benefit methodologies, and "non-monetizable" considerations, regarding the economics of climate change strategies. It is designed to demystify enough that it helps you make your own determinations as a citizen of your nation, and of the world.

My 40+ years as an environmental/sustainability advocate have been witness to a crucial race about our future: between the mounting environmental destruction of our technologies, and the potential reduction of that destruction by development and deployment of less-destructive alternatives. Climate change dynamics are no different: how fast do we need to reduce the greenhouse gas (GHG) intensity of our global economy to "win" the race – meaning not create centuries-long damages to the prospects for future generations.

The race to better manage GHGs in a timely manner is captured by the Dynamic Integrated Climate-Economy (DICE) model of 2018 Nobel laureate for economics, William D. Nordhaus: GHG growth = gross domestic product (GDP) growth plus population growth +/- GHG intensity of the economy.[3]

As humanity keeps expanding both population and the economy, managing technology development and deployment towards minimizing "GHG intensity" is critical. Nordhaus's 2013 model estimates that we face a Business As Usual (BAU = not making policy changes) likelihood of growing global emissions of carbon dioxide (CO_2) about 1.3% per year. That means 2010's ~35 billion tons (in 2018, 37.1 billion[1]) becomes ~58 billion by 2050 – a 65% increase.

"Willful waste makes woeful want."

Eliza Davison Rockefeller, mother of John D. Rockefeller, late 1800s

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[3] William D. Nordhaus, *Climate Casino: Risk, Uncertainty & Economics for a Warming World*, Yale University Press, 2013. His estimates of the three key components: GDP per capita grows 2.1%/year (yr); CO_2/GDP grows -1.6%/yr; population grows 0.9%/yr.

Climate change concerns are now central to our economy's tendencies to deplete the natural capital we need to produce wealth for good reasons, including that climate change is driven by the energy sources that underpin everything we do. Energy impacts are typically a significant portion or majority of sustainability impacts of everything we make and use (unless highly toxic materials are part of the lifecycle).

For example, a passenger car's lifecycle climate change impacts will be about 85% from the energy used as fuel, 10% to produce the car and 5% from its end-of-life disposal.[2] This also means that successful conversion to a low-carbon energy economy will have positive ripple effects towards overall sustainability, which is the critical work of protecting the next generation from this one.

We remain incredibly wasteful of energy despite nearly 50 years of awareness by thought leaders and enlightened economists that our economic health, globally and nationally/regionally, greatly benefits from being more energy and water efficient, and energy service companies specifically designed to facilitate energy savings investments.

Inefficiency remains pervasive largely because energy remains amazingly inexpensive, especially when compared to other costs of living in developed countries – frustrating market responses to impending climate chaos. That < $3/gallon vehicle fuel in the United States (U.S.) can take you safely and comfortably for up to 50 miles; that $0.10-kilowatt hour (kWh) of electricity can connect you to the world, make you comfy or manage your household; both are very underpriced for the actual value they provide.[4]

Our global advanced economies (Organisation for Economic Co-operation and Development (OECD) countries, plus China) that produced approx. 63% of 2016 CO_2 emissions[5] remain incredibly wasteful of both non-renewable energy sources and the ocean's and atmosphere's ability to resiliently absorb our wastes. And today, the world is on the verge of $90 trillion in economic development investment over the next 12 years that will determine our future GHG intensity, and climate fate.[3]

As all human wealth begins with converting something of nature into something of value to humanity, our wastefulness remains shameful – a

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[4] "Value" is a relative term relative both to your own resources, and to the alternatives for accomplishing the same result. Consider how difficult it is to achieve 50 miles travelled in good safety, comfort and privacy, via other means, and how much you are willing to pay before shifting transportation modes. Perhaps $10/gallon? How about $15?

[5] Global Carbon Atlas website, at: http://www.globalcarbonatlas.org/en/CO2-emissions. OECD countries emitted 12,550 million tonnes (Mt); China 10,151 Mt out of world total of 36,183 Mt.

moral affront to our most vulnerable humans: our youth and future generations.

An important metric of our sustainability is natural capital per capita and it is dramatically trending the wrong way. One indicator of natural capital use and depletion is the ecological footprint of humankind's demand on Earth's resources; it grew by 190% the past 50 years while global population increased 115% and vertebrate population abundance declined ~60%.[6]

Once it seemed that resource shortages would be the natural capital decline that would make us "hit the wall" and embrace meaningful environmentally-friendly changes. Instead of inputs, however, it is outputs: the subtler inability of Earth's systems to resiliently handle our wastes – resilience meaning the natural capital of that ecosystem not declining.

Our wastefulness is born not only of our technologies, and frivolities (it now seems de rigeur in the U.S. to sit in idling cars), but also of our pricing system that makes both wastefulness, and climate and air pollution extremely low cost (often zero).

It would be astonishing to any alien visitor asking how we humans decide what we do, to learn that prices determine most of it, and that they are not anywhere close to the truth – a fundamental requirement for prices to play the critical role that they do.[7] For example, the external costs of just air pollution and climate change from energy production and use is estimated to be more than the actual costs of energy – meaning our existing energy mix might be more than 100% underpriced.[8]

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[6] World Wildlife Fund (WWF), "Living Planet Report 2016" and "Living Planet Report 2018", at www.panda.org. According to the Worldometers website citing UN Population Division data, global population in 1968 was 3.55 billion and in 2018 7.63 billion: http://www.worldometers.info/world-population/world-population-by-year/.

[7] The well-established "principles of economics" are that markets are desirably efficient (i.e., effective) under specific circumstances, including perfect information by decision-makers. Sustainability economists simply say: make prices tell the truth, and we will make progress. See, for example: http://donellameadows.org/archives/advice-from-abroad-on-restructuring-electricity/.

[8] Intl. Renewable Energy Agency (IRENA), "The True Cost of Fossil Fuels: Saving on the Externalities of Pollution and Climate Change," IRENA website, 2016, at: http://www.irena.org/-/media/Files/IRENA/Agency/Publication/2016/IRENA_REmap_externality_brief_2016.pdf. The estimate of only air pollution and climate change costs from the current energy mix is \$2.2-5.9 trillion/yr, whereas total energy expenditure is approx. \$5 trillion/yr.

At its core, sustainability is a moral choice[9], partly because numbers don't provide a clear rationale for when to act, and partly because even if the full impacts of our choices were included in prices, we might remain wealthy enough to keep on doing what we like to do.

At the root of our strategic choices is a core calculation: will humanity economically gain, or lose, from delays in addressing sustainability issues like climate chaos?

There are persuasive arguments on both sides, but the "conservative" (politically conservative, not risk-averse as a true conservative position would be) argument, typically for BAU, is appropriately labeled a "risky business."[4] BAU proponents have virtually no financial loss if they are wrong and future generations unnecessarily suffer – in fact, the opposite is often true: the BAU proponents typically have a lot to gain from their point of view being adopted.[10]

This chapter will explore various perspectives on how risky is our present BAU pathway and whether we are being pennywise and pound foolish to not take stronger action.

Micro and macro 'ROI' perspectives

Climate action strategies involve whole systems that economists struggle to model; the many varied inputs make huge differences…such that you can get a model to say what you want and likely be within reasoned conjecture.

There are two fundamental ways to consider the Return on Investment (ROI) of climate-friendly investments, which I will call the micro and the macro. The micro ROI is a measure of the benefits versus costs of the specific investment (e.g., energy efficiency or fuel switching) to the investors: Does it pay for itself in a reasonable amount of time and with what risks?

The macro ROI begins with the micro and plays out the effects to an entire economy (whether local, national, or global). This will usually require

[9] See, for example, Al Gore, *The Assault on Reason*, 2007, Penguin Press: "This is a moral moment. This is not ultimately about any scientific debate or political dialogue. Ultimately it is about who we are as human beings and whether or not we have the capacity to transcend our own limitations and rise to this new occasion…"

[10] For example, estimates of the stranded assets of fossil fuel companies if climate actions and/or technology reduces demand reach $100 trillion see Giles Parkinson, "Citigroup Predicts $100 trillion in Stranded Assets if Paris Summit Succeeds," Clean Technica, 26 Aug. 2015, at: https://cleantechnica.com/2015/08/26/citigroup-predicts-100-trillion-in-stranded-assets-if-paris-summit-succeeds/.

estimating the social costs of carbon (SCC) and/or other measures of overall socio-economic health such as net employment impacts, and less monetizable but important considerations such as national security impacts, etc.

The micro ROI case largely reflects the very positive economic case for energy/water productivity (i.e., efficiency or conservation) made by environmental advocates since the 1970s, and refined to a climate focus in the 1990s.[11] Efficiency investments are more predictable than many private business investments such as research and development, market or physical expansion, or product refinements, partly because the price of energy or water saved is likely to be predictable over the payback period. Even so, efficiency remains under-utilized by both households and enterprises.

This has partly to do with a perceived (but not solidly calculated) higher internal rate of return by corporate management for investments directly into the business operations themselves instead of input efficiency. Other reasons include reticence to use borrowing capacity or cash reserves that may be needed to ride out downturns (of the company or the economy).

Serious climate action will mean dramatically more efficiency investment than today. For example, the United Nations (UN) Intergovernmental Panel on Climate Change (IPCC) 2018 report calls for increasing low-carbon and energy efficiency investments such that by 2050, humans are investing five times as much as in 2015.[12]

Micro economic analyses

A comprehensive analysis of the micro ROI in the U.S. of potential GHG reduction strategies was performed by the McKinsey & Co. for the business-based Conference Board in 2007. Their task was to map a suite of actions that would achieve national annual reductions of 1.3, 3.0 and 4.5 gigatons (Gt) of CO_2e (where e = equivalent) by 2030, when the U.S. was projected to emit 7.2 Gt/yr. It concluded that up to 4.5 Gt could be reduced "at a marginal cost of less than $50/ton (in real 2005 dollars) while maintaining comparable levels of consumer utility."

Over 250 potential investment strategies "to reduce or prevent GHG emissions" were analyzed, of which (for the 3.0 Gt "mid-range" case) many

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[11] For example, Amory B. Lovins and L. Hunter Lovins, "Climate: Making Sense, Making Money," Rocky Mountain Institute, 1998.

[12] UN IPCC, "Global warming of 1.5°C Summary for Policymakers," 2018, p. 22, at: http://www.ipcc.ch/report/sr15/. "The total annual average energy mitigation investment for the period 2015 to 2050 in pathways limiting warming to 1.5°C is estimated to be around 900 billion USD 2015."

primarily efficiency measures were determined to have a positive ROI, accounting for 40% of the GHG reductions achieved by 2030. The remaining 60% of reductions were determined to have a net cost, beyond benefits, to the investor.

Regarding the net effect on the U.S. economy, "the cumulative savings generated by the negative cost options could substantially offset the additional spending required for the options with positive marginal costs". The 3.0 Gt reduction effort would require capital investments of approx. 1.5% of the projected capital investments for the period.[5]

An updated micro-study is Project Drawdown. In 2017, it examined potential global climate change solutions for mitigation potential 2020-2050 together with their economic effects. Projects featuring high returns on investment and net economic benefits are summarized in Table 11.1:[6]

Table 11.1. Select climate change mitigation projects, modeled for implementation 2020-2050

		Net in Billions		
Project	**Carbon Emissions Reduction (Gt CO_2e)**	**Cost**	**Savings**	**Benefits**
Onshore Wind Turbines	84.6	$1225.37	$7325.0	$6099.63
Solar Farms	36.9	$ -80.50	$5023.84	$5104.44
Rooftop Solar	24.6	$ 453.14	$3457.63	$3004.49
Regenerative Agriculture	23.15	$ 57.22	$1928.10	$1870.88
Conservation Agriculture	17.35	$ 37.53	$2119.07	$2081.54
Geothermal Energy	16.6	$ -155.48	$1024.34	$1179.82
District Heating	9.38	$ 457.07	$3543.50	$3086.43
LED (light-emitting diode) Lighting Household	7.81	$ 323.52	$1729.54	$1406.02
Truck Efficiencies	6.18	$ 543.45	$2781.63	$2238.09
Heat Pumps	5.2	$ 118.71	$1546.66	$1427.95
Airplane Efficiencies	5.05	$ 662.42	$3187.8	$2525.38
LED Lighting Commercial	5.04	$ -205.05	$1089.63	$1294.68

The figures shown include the entire period of development and operation. “Net cost” and “net savings” were calculated by Project Drawdown. “Net benefits” were calculated by the author, subtracting net cost from net savings. Negative net cost means the technology choices cost less than potential substitutes.

Neither study proves that addressing climate change now instead of later is good or bad, but rather that many solutions with major climate mitigation impacts are very cost-effective now – so why not proceed with these “no-regrets” actions?

Could these high ROI investments become even more cost-effective in the future? Yes, under certain circumstances, including:

1. Higher costs of the energy or water being saved;
2. Higher rewards from carbon-emission saving investments if regulation schemes and/or carbon taxes are imposed; and/or
3. Higher effectiveness of the technologies at producing low-carbon or saving high-carbon energy (i.e., energy productivity).

As of this writing, these circumstances are highly speculative and not likely worth the wait compared to the accumulating damage costs and lock-in of carbon-wasteful infrastructure. Though important damages, such as to agricultural productivity, are projected not to occur before an approximate 3° Celsius (C) increase[7], by then it will likely be too late to cost-effectively mitigate the climate chaos.

Micro studies have traditionally used cost-benefit analyses, and/or cost-effectiveness analyses. However, their applicability to climate change calculations is low, according to the IPCC:[8]

> “…cost-benefit analysis tools can be difficult to use because of disparate impacts vs. costs and complex interconnectivity within the global social-ecological system. Some costs are relatively easily quantifiable in monetary terms but not all. Climate change impacts humans’ lives and livelihoods, culture and values and whole ecosystem. It has unpredictable feedback loops and impacts on other regions, giving rise to indirect, secondary, tertiary and opportunity costs that are typically extremely difficult to quantify.”
>
> “Monetary quantification is further complicated by the fact that costs and benefits can occur in different regions at very different times, possibly spanning centuries, while it is extremely difficult if not impossible to meaningfully estimate discount rates for future cost and benefits.”

Macro economic analyses

> "The central issue in the economics of climate change is understanding and dealing with a vast array of uncertainties…these range from those regarding economic and population growth, emissions intensities and new technologies, the carbon cycle, climate response and damages, and cascade to the costs and benefits of different policy objectives."
>
> Gillingham and Nordhaus[9]

Macro studies began with Nordhaus' 1991 DICE model. The various models in use today callout the key factors for policymakers regarding positive and negative economic effects of climate action and estimate those costs and benefits into the future.

An important tool for a macro study is calculating the SCC, also referred to as SC-CO_2; it provides an economic rationale for making climate-related expenditures without a positive micro ROI, since projects that "cost" more than micro/direct benefits to the investors are still economically justified by costing less than estimated damages from saved emissions.

The SCC is generally defined as:

> "…the economic cost associated with climate damage (or benefit) that results from the emission of an additional tonne of carbon dioxide (tCO_2)."[10]

The U.S. National Academies of Science described the commonly used integrated assessment model (IAM) for estimating the SCC as requiring these four steps:[11]

1. Projecting future global and regional population, output, and emissions;
2. Calculating the effect of emissions on temperature, sea level, and other climate variables;
3. Estimating (explicitly or implicitly) the physical impacts of climate and to the extent possible, monetizing those impacts on human welfare (i.e., estimating net climate damages); and
4. Discounting monetary damages to the year of emission.

SCC estimates have a wide range from \$10 to \$1000; some examples:[10]

- U.S. Government Interagency Working Group (2014): Median of \$38 per tonne in 2013, but as high as \$109 using forecasts of damage in the 95th percentile.[9]

- Median value of Global Social Cost of Carbon (2018): $417 per tonne CO_2. Selected country-specific values: India: $86; U.S.: $48; Saudi Arabia: $47; Brazil and China: $24.10
- William D. Nordhaus (2017): Global cost of $31 per tonne CO_2 as of 2015, in 2010 international USD, growing 3% per year to over $100 by 2050. Regional estimates range from a low of $0.91 for Russia to $6.61 for China; U.S. and the European Union (EU) estimated at $4.80.[12]

One key factor is whether a nation will include in its SCC global impacts of its emissions, or only national impacts. For example, the U.S. government is dramatically reducing the SCC calculations by including only costs to the U.S. rather than global impacts.[13]

Because the future costs and benefits that comprise the SCC are discounted to today's value over decades, the discount rate chosen has a highly determinative effect on the SCC (see the following section on discounting).

Using a SCC as a guide for climate action results in differing levels of emissions reduction: an SCC of about $50/tonne will likely push decisionmakers to reduce emissions about 20%, and at about $100/tonne a reduction of about 30-40%, but due to diminishing returns a higher SCC results in uncertain and/or marginal effects.[9]

A similar but different economic calculation is the price of carbon which, like SCC, varies according to the model and scenario used. The wide range of estimates – from $10-200 2010 dollars in the year 2100 demonstrates the difficulty of use. The price of carbon concept reflects the stringency of mitigation required at the margin (one additional tonne of emissions reduced), and so increases with mitigation efforts, assuming diminishing returns (the most favorable emissions are reduced first).[8]

A minority opinion

Julian Morris of The Reason Foundation assembled an argument in 2018 supporting BAU: Allow existing government systems (incentives and disincentives) and markets to guide climate-affecting investments, largely on a micro basis, in the absence of national or global cap and trade or similar specific climate-addressing regulatory systems. This view was partly based on his assessment that the steps involved in calculating a meaningful SCC are all "fraught with difficulty."[13]

Morris' key findings:

- The SCC calculations rely on too many unknown and unknowable variables beginning with future human population, deployment of energy-using technologies, types of technologies used to create energy, and energy efficiencies.
- "The climate is likely much less sensitive to increased emissions of GHGs than has been presumed in most IAMs."
- The benefits of climate change may be greater than the costs for the foreseeable future. (Examples: (1) more deaths and energy use results from cold weather than hot weather; (2) positive fertilization effect of higher atmospheric CO_2 on agricultural productivity).
- The results from testing future global temperature prediction models "cast serious doubt on the predictive ability of the models".
- Sufficient progress will be made without explicit actions because energy efficiency innovations occur since they are better products and trends are toward dematerialization (e.g., books become electronic).

Morris specifically assails "taking action now" because future required GHG reductions will be costlier if we do not. He claims that this strategy presumes "both significant increases in baseline emissions and a need to dramatically reduce such emissions. Continued innovation will almost certainly result in lower emissions per unit of output in the future, so the costs of reducing a unit of GHG emissions in the future will be lower than they are today."

The majority of opinions: Act now

> "We can't afford to ignore this crisis. It's as if we're watching as we fly slow motion toward a giant mountain. We can see the crash coming, but we're sitting on our hands instead of altering course. It's time to turn the wheel."
>
> Henry M. Paulson Jr., 2015[14]

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[13] Julian Morris, "Climate Change, Catastrophe, Regulation and the Social Cost of Carbon," Reason Foundation, 8 March 2018, at: https://reason.org/policy-study/climate-change-catastrophe-regulation-and-the-social-cost-of-carbon/.

> "Our report finds that the costs of achieving a fixed climate change goal would be 40 percent larger if we waited a decade to take action. And those costs could grow exponentially with a longer wait."
>
> U.S. Government, President's Council of Economic Advisors, 2014:[14]

Morris' view is contrary to the majority of conclusions by comprehensive analyses, to wit:

- UN Secretary-General, 2018: "If we do not change course by 2020, we risk missing the point where we can avoid runaway climate change."[15]
- UN Green Industrial Policy, 2017: "It is widely agreed that delayed implementation of mitigation measures will make it much more difficult and costly, if not impossible, to reach given climate targets."[16]
- Risky Business Project, 2016: "Seriously addressing climate change requires reducing GHGs by at least 80% by 2050 in the U.S. and across all major economies. We find that this goal is technically and economically achievable using commercial or near-commercial technology."[4]
- World Resources Institute, 2014: "Delaying action will have significant economic impacts: climate change itself constitutes a significant risk to the nation's economy. With each decade that the U.S. delays acting on climate change, it is estimated that the cost of mitigation increases by 40%."[17]
- International Energy Agency, 2011: For every $1 not spent on cleaner electric power by 2020, approx. $4.30 will need to be spent after 2020 to compensate for the carbon emissions.[18]
- Australian National University's Centre for Climate Economics and Policy, 2015: "Taking it easy at first and going for stronger action later would likely come at a high economic cost. A range of models have found that delaying global mitigation by 15 years could double or triple the cost of keeping to an overall carbon budget."[19]

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[14] Executive Office of the President of the United States, "The Cost of Delaying Action to Stem Climate Change," July 2014, at: https://obamawhitehouse.archives.gov/sites/default/files/docs/the_cost_of_delaying_action_to_stem_climate_change.pdf. See also: Jason Furman, Chair of the President's Council of Economic Advisors, and John Podesta, White House Chief of Staff, "We Can't Wait: The Cost of Delaying Action to Stem Climate Change," Huffington Post, 28 Sept 2014, at: https://www.huffingtonpost.com/jason-furnan/climate-change-costs-of-delay_b_5629796.html.

- UN IPCC, 2018:[8]
  - Global warming is likely to reach 1.5°C between 2030 and 2052 if it continues to increase at the current rate.
  - Climate-related risks for natural and human systems are higher for global warming of 1.5°C than at present, but lower than 2.0°C.
  - Risks to global aggregated economic growth due to climate change impacts are projected to be lower at 1.5°C than 2.0°C.
  - Pathways limiting global warming to 1.5°C with no or limited overshoot would require rapid and far-reaching transitions in energy, land, urban and infrastructure and industrial systems.

One of many in-depth analyses favoring immediate climate action is the 2018 report by The Global Commission on Climate and Economy, a project led by the World Resources Institute. It examined the macro economic impacts of actions to reach the Paris Accord's goals of a 2°C limit to global warming by 2050, concluding that:

- "…ambitious climate action does not need to cost more than BAU growth."
- In the next 10-15 years, $90 trillion will be invested in human infrastructure; ensuring it is sustainable will be a critical determinant of future growth and prosperity and will largely determine the ability to hold global warming to 2°C.
- The path of delayed action could result in $12 trillion of stranded assets when actions are taken later.[3]

The project found that a decisive shift to a low-carbon economy would result in multiple significant benefits compared to BAU, during 2018-2030. The shift included a "meaningful" carbon price of $40-80/tonne rising to $50-100. Benefits included:

- Avoiding over 700,000 premature deaths from air pollution;
- Raise U.S. $2.8 trillion in carbon price revenues and fossil fuel subsidy savings ($373 billion/year) to reinvest in public priorities;
- Higher global GDP growth;
- A direct economic gain of $26 trillion by 2030 and generation of over 65 million additional low-carbon jobs;
- Increase female employment and labor participation;

- Climate resilient water supply and sanitation services could save the lives of > 360,000 children under 5 years of age;
- Each $1 invested in energy efficiency is estimated to save $2 in new powerplant and distribution costs;
- More compact urban areas improve residents' access to jobs/services/amenities and could reduce global infrastructure requirements by over $3 trillion to 2030; and
- Sustainable food and land use business models could be worth up to $2.3 trillion and provide up to 70 million jobs by 2030.

Skewering the future by skewing damage cost estimates via discounting

The IPCC has used a 100-year timeframe for understanding the Global Warming Potential (GWP) of GHGs, though it noted in 2013 that there is no compelling reason not to use a 20-year timeframe, for which it has also computed GWP values.[15] Since CO_2 emissions are climate damaging for 5-200 years[16] (in the concentrations now emitted by humankind well beyond the ability of Earth's waste sinks to absorb them), economic estimates of future damages partly rely on the value of 100-year damage estimates to use carbon emitters today.

According to Nordhaus, "It is well known that the discount rate has an important impact on the SCC."[12] Discounting the value of future costs and benefits of projects with multi-generational impacts – whether dams, climate change, nuclear waste storage, or infrastructure projects – is accepted as a rational "discounted utilitarianism" approach, but is justifiably controversial in its effect: that the future does not count very much today.

[15] CO_2 is one of six GHG categories. According to the IPCC 2014 report, both CO_2 and N_2O have roughly the same GWP for both the 20-yr and 100-yr timeframes. Methane, much more potent a GHG, has a global warming "lifetime" of only 12.4 yrs and so is 84 times more potent as a GHG than CO_2 in the 20-yr timeframe, and 34 times more potent in a 100-yr timeframe. Perfluoromethane (CF_4) has a > 50,000 yr "lifetime", so its 100-yr GWP is 6630 compared to 4880 for the first 20 yrs. Source: UN IPCC, "Climate Change 2014 Synthesis Report," p. 87.

[16] IPCC, Working Group 1, "The Scientific Basis C.1.", at: https://www.ipcc.ch/ipccreports/tar/wg1/016.htm. The IPCC noted that: "no single lifetime can be defined for CO_2 because of the different rates of uptake by different removal processes." Atmospheric lifetimes for other GHGs: methane: 12 yrs; nitrous oxide: 114 yrs; chlorofluorcarbon-11: 45 yrs; hydro-chlorofluorocarbon-23: 260 yrs; perfluoromethane: > 50,000 yrs.

Discount rates deploy the math of compound interest – useful at times, but not always. Because a consistent growth rate grows each year upon itself, so to speak, small differences become big differences over time.

For example, two discount rates, 1.4% and 2.7%, were proposed by the first comprehensive national economic analysis of climate change impacts, the Stern Review (2007). Though 2.7% is approx. double 1.4%, in the 100th year the difference is about 3.5 times, and over 200 years, the difference is about a factor of 13.[20]

Table 11.2. Discount rate effects

Discount Rate	Value Today of $100 Million in 50 Years
1%:	$60.8 million
4%:	$14.1 million
7%:	$3.4 million
10%:	$0.85 million

These figures apply to $100 million in benefits from climate actions, such as energy efficiency investments, or $100 million in economic damages.[7]

At best, discounted costs of climate change can result in only a vague guide for our actions today. As noted by the Political Economy Research Institute of the University of Massachusetts Amherst:

> "In cost-benefit analysis, the normative objective is efficiency, defined as maximization of the net benefits minus costs converted into present values by means of a discount rate. In the case of climate change, such calculations entail multiple difficulties, simplification and arbitrary assumptions."[21]

For example, what is the value to us today of a projection, such as that made by Nextgen Climate, that a BAU path will reduce the lifetime income of the current U.S. millennial generation by $8.8 trillion?[22] Is it rational to use discounting to credit that loss at just a few pennies on the dollar?

The discount rate used for climate change is called a social discount rate (SDR) that is comprised of three components: economic growth, a human preference for today over the future, and a human aversion to inequality. For economist Nordhaus, it added up to 4-5%; for UK economist Nicolas Stem 1.4%.[23]

Harvard economist Martin Weitzman argues for a different approach to human-induced potential future catastrophes:[24]

> "The economic uniqueness of the climate-change problem is not just that today's decisions have difficult-to-reverse impacts that will be felt very far

> out into the future, thereby straining the concept of time discounting and placing a heavy burden on the choice of an interest rate…the climate science seems to be saying that the probability of a disastrous collapse of planetary welfare is non-negligible, even if this tiny probability is not objectively knowable."

There is a limited connection between how people want people in the future considered in today's decisions, and discount rate determinations such as the market-based costs of money. That connection is further strained by prices that do not tell the truth, which skews many of the economic foundations upon which discount rates are estimated. As noted in the journal *The Future of Children*:

> "A common economic formula recommends giving up only 5 cents today for every dollar of benefits 100 years into the future; we call this discounting the future. Underlying this approach is the assumption that future generations will be much better off than our own, just as we are much wealthier than our ancestors were. Would our descendants agree with this approach?"[23]

The authors (economists and climate experts) found three reasons for people today to put a higher value on future benefits from acting on climate change now:

1. People disagree considerably about the correct discount rate. Other plausible interpretations of society's preferences or observed data could increase the weight we place on future benefits by as much as a factor of five.
2. We may have failed to correctly value future climate change impacts, particularly those related to the loss of environmental amenities that have no close monetary substitutes.
3. We may not be properly valuing the risk that a warming climate could cause sudden and catastrophic changes that would drastically alter the size of the population.

Ultimately, the authors conclude that many of the choices about how we value future generations' welfare come down to ethical questions, and many of the decisions we must make come down to societal preferences – all of which are difficult to extract from data or theory.

A far better substitute would be democratic processes, e.g., legislation or other ways of determining how to value far-in-the-future damages. It is an ethical choice, not something that flows from economics.[20] Even the sliding discount scale to 1.07% after 76 years suggested by the UK government for health,[25] while an improvement, seems arbitrary and capricious.

I personally cannot see telling my progeny that I heavily discounted the value of damages I was causing to the natural capital they need to thrive just because it was accepted economic practice for cost-benefit analysis of projects within my own lifetime. Discounting techniques are not properly applied to climate change or other multi-generational impacts of our choices today.

An alternative cost perspective: Costs of GHG removal

It could be simpler, though potentially misleading, to estimate the economic costs of GHG emissions using the costs of removing emissions from the atmosphere. If a ton of carbon can be removed from the atmosphere for, say, $20, is that a better guide than SCC estimates? However, estimates of how much carbon can be removed show less than 20% of annual emissions could actually be mitigated.

Various negative emission technologies (NETs) have been deployed or are under development such that estimates of costs and potential capacity have been made by the U.S. National Academy of Sciences.[26] Its committee that published a NETs research agenda in 2018 categorized likely cost per ton of CO_2 sequestered as "Low" if < $20/tonne; "Medium" if > $20 but < $100; and "High" if > $100.

Low costs were estimated for changes to management strategies that would sequester carbon in ecosystems: coastal blue carbon, afforestation/reforestation, forest management and (low to medium costs) agricultural practices to enhance soil carbon storage. Medium costs were estimated for bio-energy with carbon capture and sequestration (BECCS) and medium- to high-cost carbon mineralization. High costs were estimated for direct air capture, the least known for efficacy or ultimate deployment potential.

The committee concluded that BECCS and the low-cost NETs are ready for large-scale deployment, but that serious non-cost constraints can inhibit deployment to the maximum "safe and economical" potentials shown below by a factor or two or more.

Consider these annual maximums in the context of current emissions of approx. 50 Gt/ CO_2/yr globally. At maximum deployment, only < 20% of current annual emissions could be mitigated. Figures shown are Gt/CO_2/year:

- Coastal Blue Carbon: 0.13
- Afforestation/Reforestation: 1.0
- Forest management: 1.5
- Agricultural practices: 3.0
- BECCS: 3.5-5.2

These NETs come with co-benefits that can reduce their total social costs, but no monetized estimates were made for either the co-benefits or negative externalities such as:

- Increased forest productivity via changes in forest management;
- Improved agricultural productivity, soil nitrogen retention and soil water holding capacity; and
- Liquid fuel production and electricity generation (BECCS).

The committee concluded that:

> "…all existing safe and economical NETs and mitigation options together do not have sufficient capacity to meet the Paris agreement target…Any argument to delay mitigation efforts because NETs will provide a backstop drastically misrepresents their current capacities and the likely pace of research progress."

Where to place our bets?

> "…some people advocate for doing nothing at all, forever, or at least for a long time…that proposal appears to me to be a reckless gamble (the wreck the world approach)."
>
> William D. Nordhaus, 2013[7]

> "The drop in the cost of clean technology has gone far beyond all expectations, tipping the economics in favor of decarbonisation."
>
> Laurence Tubiana, 2017[17]

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[17] Laurence Tubiana, Preface to: Laurent Fournie, et al., Artelys, "Cleaner, Smarter, Cheaper Responding to Opportunities in Europe's Changing Energy System", Energy Union Choices, 2017, at: https://www.energyunionchoices.eu/cleanersmartercheaper/. Mr. Tubiana is CEO of the European Climate Foundation.

Are there any conditions under which climate change action should be delayed? Perhaps if further major cost breakthroughs in low-carbon energy technologies were likely, waiting would make sense.

It is unpredictable how much more low-carbon energy system costs might drop in the future. An EU analysis (Table 11.3) found that a 15% to 55% reduction in capital investment costs may be achieved for offshore wind turbines, photovoltaic solar, solar thermal electricity and ocean energy between 2015 and 2030 but that cost reduction may then slow down. Cost reductions for onshore wind, geothermal, biomass combined heat-power plants were projected to be "less pronounced".[27]

Whether these potential cost savings by waiting to act can offset the growing volume of climate change damages is nearly impossible to determine.

Table 11.3. Capital cost projections, renewable energy systems

Energy system	**2015**	**2030**	**2050**	**Reduction 2015-2050 % of 2015 price**
Utility-scale PV w/o tracking	1020	720	500	51%
Offshore wind, monopole, med. distance	3500	2850	2640	25%
Onshore wind, medium specific capacity & hub height	1350	1260	1190	12%
Flash geothermal	3540	3260	3060	14%

Baseline Projections of European Commission, 2018[27]
Figures in EUR/kW

The EU's Energy Union Choices consortium found in 2017 that because of cost reductions to date and signs pointing in the "direction of further improvements," the EU could increase its planned use of low-carbon electricity in 2030 from 49% to 61%, concluding that among future scenarios, "the scenario with the deepest emissions reductions is also the scenario that can boast the best economic results."[28]

Costly carbon capture and sequestration (CCS) technologies are described as already reaching the limits of physics (though economies of scale seem likely to reduce costs).[29]

The key factors in an analysis of whether delaying climate change action costs us, or benefits us, are:

- Technologies (development and more importantly, widespread rapid deployment)
    - Low-carbon technologies that reduce climate impacts of human activities – namely energy and water efficiency and low-carbon energy sources.
    - Mitigation technologies – carbon removal or sequestration systems – NETs.
- Impacts
    - Ecological (natural capital) impacts (especially irreversible impacts)
    - Human impacts – especially on "human capital" which is the ability of humans to do productive work based on their health, skills, and social competence/networks.
    - Economic impacts – both the macroeconomic impacts of national/global economic growth or decline, and the distributive impacts on people's lives – which is likely to vary widely according to location, wealth, and climate resilience of communities, enterprises, and families/individuals.

For each of these considerations, recent findings include:

- Low-carbon technologies
    - Energy efficiency investments can produce a triple dividend: greater energy savings, fewer emissions, and more jobs.[16]
    - Doubling the share of renewables in the global energy mix by 2030 compared to BAU would reduce annual costs of air pollution and climate change by $1.2-4.2 trillion by 2030 – saving from 4-15 times the costs associated with installing the renewables.[18]
    - U.S. clean energy investments required would generate 800,000 construction jobs by 2050, offsetting 270,000 job losses in coal mining and oil/gas industries.[4]
    - The UK National Infrastructure Commission concluded in 2018 that the same home energy services that people use today could

[18] Intl. Renewable Energy Agency (IRENA), "The True Cost of Fossil Fuels: Saving on the Externalities of Pollution and Climate Change," IRENA website, 2016, at: http://www.irena.org/-/media/Files/IRENA/Agency/Publication/2016/ IRENA_REmap_externality_brief_2016.pdf. The annual savings are $1-3.2 trillion from air pollution and $0.2-1 trillion from climate change impacts, compared to the BAU assumption that fossil fuel use increases 40% from 2010-2030.

    be provided by 2050 through a low-carbon infrastructure economy at no additional cost.[30]

- Ecological impacts
    - At a 2°C increase, 18% of insects, 16% of plants and 8% of vertebrates lose over half of their climatically determined geographic range, about twice as much as 1.5°C increase.[8]
    - "Impacts will include ocean acidification and the death of coral reefs, and the contamination of coastal aquifers by sea-water intrusion. These changes will have severe societal impacts and major economic consequences."[21]
- Human impacts
    - Security
        - "Climate change is one of the most pervasive global threats to peace, affecting security, development and peace building."[31]
    - Temperature and health
        - In the U.S., BAU means the average American will experience 45-96 days with high temperatures over 95° Fahrenheit (F) by 2100; people lacking air conditioning or needing to work outdoors will face health risks.[32]
        - Temperature increases have a large effect on the GDP of poor countries – effects could be particularly severe for children who already live in warm climates that will see a disproportional rise in hot days.[33]
        - Increasing frequency of high temperature days is likely to diminish children's ability to learn and adult ability to perform mental tasks.[19]
    - Climate migrants and food insecurity
        - "If no action is taken, experts predict that there may be more than 140 million climate migrants moving within their countries by 2050. More than half of those people are expected to be in Sub-Saharan Africa. If we act now, we could reduce the number of people forced to move due to climate change by as much as 80%."[34]

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[19] Joshua Graff Zivin and Jeffrey Schrader, "Temperature Extremes, Health and Human Capital," *The Future of Children*, Spring 2016, pp. 31-50, at: https://www.jstor.org/stable/43755229?refreqid=excelsior%3Aa2511d99b2344f80da305c62fc23558a&seq=1#metadata_info_tab_contents. For example, office worker productivity is estimated to decline 5% from a temperature increase from 21°C to 27°C.

        - "The main reason people are moving [north from Central America] is because they do not have anything to eat. This has a strong link to climate change – we are seeing tremendous climate instability that is radically changing food security in the region."[20]
- Economic impacts
    - Macro-economic impacts
        - "By 2050, the loss in consumption relative to a utopian scenario" [no climate action taken and no damages from climate change] "ranges from about 0.5% to just over 5%, depending on the depth of emissions cuts."[23]
        - "…temperature may have a strong impact on economic activity, reducing Gross Domestic Production (GDP) by as much as 20% worldwide by 2100."[21]
    - Agricultural resources
        - For the U.S., BAU likely means gains for farmers in the north that are more than offset by risks to farmers in the South, Great Plains and Midwest of 50-70% loss of annual corn, soy, cotton, and wheat yields, absent agricultural adaptation.[32]
    - Potential costs
        - In the U.S., BAU likely means $66-106 billion of existing coastal property will be below sea level by 2050, increasing to $238-507 billion by 2100.[32] Approximately 300,000 buildings could be at risk of chronic disruptive flooding by 2047, and by 2100, 2.5 million buildings worth over $1 trillion today.[35]
        - Sea level rise will continue well beyond 2100 even with temperature increase limited to 1.5°C.[8]

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[20] Quoted is Robert Albro, researcher at Center for Latin American and Latino Studies at American University, in Oliver Milman, Emily Holden and David Agren, "The unseen driver behind the migrant caravan: climate change", *The Guardian*, 30 October 2018, at: https://www.theguardian.com/world/2018/oct/30/migrant-caravan-causes-climate-change-central-america.

[21] Dawn L. Woodard, et al., University of California, Irvine, "Economic carbon cycle feedbacks may offset additional warming from natural feedbacks," Proceedings of the National Academy of Sciences, 25 Oct. 2018, at: www.pnas.org/cgi/doi/10.1073/pnas.1805187115. The authors found that the expected decline in economic activity due to climate change could offset climate change enhancing feedbacks in nature such as "decreases in carbon uptake by terrestrial and marine ecosystems."

- Economic growth from climate action, i.e., Green Growth or Sustainable Development
    - Investments in green growth in Uganda could increase GDP by an estimated 10% by 2020 ($3.4 billion) compared to BAU.[34]
    - The "High" renewables investment scenario will produce 1 million more jobs by 2030, and 2 million more by 2050, than BAU. Households would realize energy bill savings of $41 billion by 2050.[36]

Non-monetizable considerations

The remainder of this chapter will address important considerations typically not dealt with by macro analyses. These factors, while critical to humanity's climate welfare, are hard to value in economic models, but deserve consideration, just as in traditional cost-effectiveness analysis.

Other important hard-to-monetize considerations, beyond those touched upon here, include the energy-water nexus, the value to some people of individual freedoms via unregulated capitalism, inequality of wealth and incomes, gender and indigenous people's rights, and advancement opportunities, all of which are included in sustainable economic development (green growth) initiatives.

Energy price increases

It is reasonable to expect that serious climate action would involve energy price increases from one or more drivers, including deployment of higher cost technologies, carbon taxes, or regulations such as a cap and trade system. Nordhaus, for example, notes that steps to slow climate change "will require using costlier technologies and policies and will therefore reduce real incomes".[7]

Prices are also likely to rise if climate action includes, as it should, elimination of the $550 billion/year fossil fuel subsidies presently granted by governments – which results in an effective SCC of a negative $15/tonne (the opposite of what is needed for global capital markets to work well).[37]

Nordhaus summarizes:

> "Economics points to one inconvenient truth about climate-change policy: for any policy to be effective, it must raise the market price of CO_2 and other GHG emissions…the incentive must be for everyone millions of firms and billions of people spending trillions of dollars to increasingly replace their

current fossil-fuel driven consumption with low carbon activities. The most effective incentive is a high price for carbon."[7]

Additional price increases may result from the deployment of costly carbon sequestration technologies that reduce powerplant efficiency 7-10% or more (the "energy penalty")[38].[22]

For example, The International Energy Agency notes that "the well-below 2°C target" of the Paris Accord requires CCS.[38] However, U.S. levelized (lifecycle) electricity costs from state-of-the-art ultra-supercritical new coal plants are estimated to rise from $92.46/MWh (megawatt/hour = 1000 kilowatt hours) to $152.34/MWh with CCS systems.[29] The price increases would be challenging for people already living in "energy poverty" – including up to 15% of populations in developed countries.[3]

How much energy price increases might affect an economy is situational by country, business cycle, and what economists call price elasticity – the change in demand for a product if its price increases.

For example, in 2006 the U.S. Congressional Budget Office estimated that dramatic energy price increases since 2003 had only affected national GDP by about one quarter of one percent per year.[39] A dramatically different outcome was offered by a model created in 2015 for the U.S. National Rural Electric Cooperative Association – it predicted a national loss of 18-31 million jobs between 2020 and 2040 if electricity prices increased just 10%.[40]

The economic effect will also depend on the predictability of the price increases. "Energy price shocks" such as those of the 1970s can clearly create economic dislocations and potential recessions, but gradual and/or planned changes allow cost-effective adaptation.

If people consume less energy due to higher prices, but instead spend on products or services more locally produced, the higher economic multiplier of local products can counterbalance or exceed the loss to energy producing entities (see following import substitution discussion).

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[22] Existing CCS systems had an energy penalty of 20-30%   see John Kemp, "Carbon capture's energy penalty problem: Kemp," Reuters, 6 Oct. 2014, at: https://www.reuters.com/article/us-carboncapture-economics-kemp/carbon-captures-energy-penalty-problem-kemp-idUSKCN0HV1VD20141006.
A lifecycle examination of CCS for a coal powerplant found that an initial 85% carbon capture rate was overall a 70% capture rate because of the additional energy expenditures required for the CCS system   see: Friends of the Earth   Denmark (NOAH), "Information about Carbon Capture and Storage   CCS", undated, accessed 1 November 2018, at: http://ccs-info.org/climate-efficiency.html.

Energy productivity technologies allow consumers to pay higher prices per unit of energy. If your car takes you twice as far per unit of fuel, you can pay up to twice as much per unit and not be worse off. Thus, energy productivity mandates can indirectly support potential fuel switching to more expensive low-carbon fuels if needed, with little adverse impact.

Much of the economic effect of carbon taxes, for example, can be mitigated by making the new taxes "revenue neutral", i.e., keeping government revenues approx. the same but changing who pays the taxes, as was done in British Columbia when it established carbon taxes in 2008.[23]

As "necessity is the mother of invention," a case can be made that increasing energy prices will stimulate development and deployment of globally-competitive energy efficient products that can boost an economy through global sales, as well as domestic deployment that provides cost-effective competitiveness (i.e., the energy productivity leaps from investments that would not otherwise be made allow products or services of any type to have a lower cost basis than global competitors' products). Competitively low "unit costs" of energy (comprised of prices and productivity) in the EU demonstrate this effect.[24]

Can any of these uncertainties be accurately enough forecast such that energy price increases from climate action would have predictable economic effects? I believe the dynamics are too variable to monetize it.

Economic benefits of imported energy substitution

The Rocky Mountain Institute first pointed out in the early 1980s that economic health is about both inflow and outflow of wealth; the favorite analogy was that if you have a leak in your vehicle's gasoline tank, fix it

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[23] See, for example, A. Yamakazi, "It's not a job killing policy The case of BC's revenue neutral carbon tax," Sustainable Prosperity Research Note, 2016, at: www.sustainableprosperity.ca/content/its-not-job-killing-policy-case-bcs-revenue-neutral-carbon-tax; and Coral Davenport, "After Nobel in Economics, William Nordhaus Talks About Who's Getting His Pollution-Tax Ideas Right," *The New York Times,* 13 Oct. 2018, at: https://www.nytimes.com/2018/10/13/climate/nordhaus-carbon-tax-interview.html.

[24] Emmanuelle Maincent, et al., "Are high energy prices harming Europe's competitiveness? Assessing energy cost competitiveness in Europe," 22 January 2015, at: https://voxeu.org/article/are-high-energy-prices-harming-europe-s-competitiveness-assessing-energy-cost-competitiveness-europe. The authors are economic analysts for the EU Commissions and warn that the competitive advantage of energy productivity is slipping away as China and other competitors improve energy productivity and so warn against additional energy price increases.

instead of continually wasting unused fuel. And the biggest "leak" of wealth out of most community/regional economies is energy expenditures.

Thus, the core components of climate action–energy efficiency and locally-derived non-carbon energy sources – are an important strategy for economic health. Further, the economic lifecycle of efficiency or renewables often includes local enterprises. As noted by a study on the economic advantages of climate action for Canada's "Atlantic Islands":[41]

> "Because of the 'multiplier effects,' every dollar spent on a locally owned business creates 2-4 times more jobs and other economic benefits than a dollar spent in a similar non-locally owned business."

For example, energy [in 2012] cost Bridgewater, Nova Scotia $88 million per year. Through the import replacement of energy by local sources, the Energize Bridgewater project [comprising about CAN $500 million invested in energy efficiency and local sources] is expected to save over $2 billion in energy costs over the next 33 years and reduce GHG emissions by 80%."

Consider the potential economic health benefits that can be expected via energy import substitution for countries now heavily dependent on energy imports, including (for 2014 or 2015):[42]

- "Euro area" (average of 60% dependent upon imported energy):
  - Austria: 64%
  - Belgium: 80%
  - Ireland: 86%
  - Italy: 76%
  - Portugal: 77%
  - Spain: 71%
- Namibia: 74%
- Turkey: 75%
- Republic of Korea: 82%
- Jamaica: 82%
- Japan: 93%

For example, Morocco imported 95% of its energy in 2011, but has strengthened its economy by switching to nearly one-third from domestic renewable sources – including 15% of electricity from solar PV by 2020, reducing GHG emissions by 3.7 million tonnes/year.

National security/Energy security

What is energy security (or any type of security, e.g., financial security or cultural security) worth to us as individuals, communities or nations? Like ecosystems, we treasure it, but its value is not monetizable.

Energy insecurity can have drastic consequences. It was an important reason the Japanese attacked Pearl Harbor in 1941 and continues to drive foreign policies worldwide.

The concept has recently broadened from a focus on imported energy dependence to other critical aspects such as flexible global energy markets, internet security and terrorism[43] and climate change,[44] but monetized values for it remain awkward.[25]

Strong climate action that promotes domestic energy sources over foreign, especially if promoting distributed sources over centralized grids,[26] can greatly enhance energy and economic security as important co-benefits. Energy efficiency does as well: The EU notes that "moderating energy demand is one of the most effective tools to reduce the EU's energy dependency and exposure to price hikes."[45]

What would it be worth to the economy or citizens' peace of mind, for example, to reduce the 93% importation of nuclear powerplant fuels of the U.S.?[27]

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[25] Environmental and Energy Study Institute (EESI), "Issue Brief: The National Security Impacts of Climate Change," 20 Dec. 2017, at: https://www.eesi.org/papers/view/issue-brief-the-national-security-impacts-of-climate-change. A "monopsony" premium paid by U.S. consumers has been ascribed to imported oil of between $7.86 to $12.50/oil barrel (bbl).

[26] See, for example, (1) Tim Buckley and Simon Nicholas, Institute for Energy Economics and Financial Analysis (IEEFA), "Japan: Greater Energy Security through Renewables Electricity Transformation in a Post-nuclear Economy," March 2017, at: http://ieefa.org/wp-content/uploads/2017/03/Japan_-Greater-Energy-Security-Through-Renewables-_March-2017.pdf; and (2) Amory B. Lovins et al., Small is Profitable The Hidden Economic Benefits of Making Electrical Resources the Right Size," Rocky Mountain Institute, 2002, at: https://rmi.org/wp-content/uploads/2017/04/OCS_SmallisProfitable_2002.pdf.

[27] In 2018, national security discussions include setting a 25% minimum domestic content requirement see: Steven Mufson, "Trump officials weigh limits on uranium, invoking national security," The Washington Post, 18 July 2018, at website of Macomb Daily: https://www.macombdaily.com/business/trump-officials-weigh-limits-on-uranium-invoking-national-security/article_926a42a1-322e-5778-b273-3b2621df5375.html.

Environmental/Social justice

What is the value of less inequality and/or poverty? Or more equitable distribution of environmental impacts, which are typically concentrated on the poor? Is significant progress in these areas worth some economic sacrifice?[28] How much?

It is widely recognized that the majority of climate change costs are likely to fall upon the poor, especially those living in already hot areas such as sub-Saharan Africa.[29]

The Global Commission on Climate and Economy lists humanity's key challenges by 2050 as:

1. Feeding a global population of approx.10 billion;
2. Providing clean and affordable electricity/water/sanitation;
3. Upgrade skills;
4. Secure better health; and
5. Closing the gender gap.[30]

What is progress in these endeavors worth? Cost-effective climate action today is very likely to support progress; BAU is likely to hinder it.

Embracing cooperative *vs* non-cooperative behavior?

What's the economic value of leading by example? In the case of climate change – that means doing the right things so that other countries will also do so – especially when you have a lot to lose if they do not.

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[28] For example, economist Thomas Piketty proposed a 2% global wealth tax to reduce economic inequality because of its overall societal costs. Thomas Piketty, *Capital in the 21st Century*, Belknap Press, 2014.

[29] For examples, see chapter eight, *Traditional Knowledge and Climate Change Challenges: Anambra State, Nigeria Case Study* by C. Chinweze and chapter six, *Ecological and Infectious Disease Impacts of Hydropower in Sub-Saharan Africa* by B. Taylor in **Demystifying Climate Risk Volume I: Environmental, Health, and Societal Implications** (LeBlanc, C. ed., Cambridge Scholars Publishing, 2017).

[30] The Global Commission on Climate and Economy (managing partner: World Resources Institute), "Unlocking the Inclusive Growth Story of the 21st Century: Accelerating Climate Action in Urgent Times," August 2018, at: https://newclimateeconomy.report/2018/wp-content/uploads/sites/6/2018/09/NCE_2018_FULL-REPORT.pdf. These are consistent with the UN's Sustainable Development Goals (SDGs) see https://unstats.un.org/sdgs/indicators/indicators-list/.

For example, an in-depth study of Australia's climate change strategy options found that:

> "Australia stands to gain from early and strong global climate action and needs to contribute its fair share…It is vulnerable to climate change and all sides of politics agree that strong global action is in the national interest."[46]

Nordhaus called this dilemma "the problem of non-cooperative behavior," wherein "national efforts will be determined by only the national SCCs rather than the global SCC and will therefore be much lower."[12]

It is a short-sighted pathway the U.S. federal government appears to be embarking upon. Will it be beneficial to citizens in the long-run, especially if the rest of the world follows with its own non-cooperative behavior?

Conclusion

> The best throw of the dice is to throw them away English proverb
> Quoted by William D. Nordhaus, 2013[7]

> "Climate-related risks to health, livelihoods, food security, water supply, human security, and economic growth increase with 1.5°C [increase over pre-industrial global temperature average] and increase further with 2°C."
> IPCC, 2018[8]

"Overshoot and collapse" is a scary phrase developed by the Club of Rome's "Limits to Growth" team in the early 1970s to describe their models' predictions of how ecosystems will likely fare with BAU-like scenarios. It is a haunting concept because it describes a common pattern among individuals to create big problems in their own lives by overreach, and because it calls out an inherent human foible: not recognizing we have exceeded our bounds before it is too late. Nordhaus cautions that "Waiting for the right climate change answer is a perilous course – it is like driving 100 miles per hour with your headlights off on a foggy night and hoping there are no curves."[7]

"How a society treats its most vulnerable is always the measure of its humanity," noted UK Ambassador to the UN Matthew Rycroft in 2015, paraphrasing Gandhi.[31] When considering multi-generational pollutants like

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[31] https://www.gov.uk/government/speeches/how-a-society-treats-its-most-vulnerable-is-always-the-measure-of-its-humanity. M. Gandhi said, "The true measure of any society can be found in how it treats its most vulnerable members."

GHGs, the "most vulnerable" are easily identified: those not yet born. Are we up to the task? People living "conservatively" are risk-averse; they build in buffers from disasters by doing things like buying insurance, having sufficient savings, developing self-resilient and wide-ranging skill-sets, becoming life-long learners so situational assessments benefit from the best information available, and avoid catastrophes to the extent possible, e.g., "don't drink and drive".

Climate change and other sustainability concerns have turned political definitions of "conservative" and "liberal" upside down. True conservatives should be clamoring for green industrial policies and aggressive climate action as the least risky pathways. Instead, they have become radical chance-takers. When combined with the likely huge economic competitiveness advantages of taking strong action now, climate change risk reduction from strong, smart, 21st-century-adept adjustments to global BAU is close to a "no-brainer" if only we have the "guts" to get on with it.

Multiple considerations make climate action a positive economic prospect: the generally high ROI of energy and water efficiency investments; the crucial need for development patterns of the coming decades to set-up people and enterprises to thrive with reduced energy/GHG intensity; and the economic development advantages of imported energy substitution and distributed energy systems – both nationally and regionally. These strong economic advantages, combined with the well-documented ripple effect of climate action on other critical sustainability goals and health challenges from reduction of lifecycle fossil fuel air pollution (especially air pollution), make a strong economic case for the type of serious action called for by whole-system proposals such as those of Drawdown Project, the Global Commission on Climate and Economy, and the Risky Business Project.

Our future is too important to be left to either wildly imperfect prices, and/or markets not designed to address this problem, and/or misplaced technological optimism.

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45. EU Commission law website EUR-Lex, "Communication from the Commission to the European Parliament and the Council: European Energy Security Strategy," 2014, at: https://eur-lex.europa.eu/legal-content/EN/ALL/?uri=CELEX:52014DC0330&qid=1407855611566.
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CHAPTER TWELVE

THE ROLE OF ETHICS AND GOVERNANCE IN THE PURSUIT OF CLIMATE SCIENCE

CAROLE A. LEBLANC, PH.D.[1]

"We make a living by what we get, but we make a life by what we give."
Sir Winston Churchill (1874-1965)

Abstract

This paper presents a brief examination of the sometimes-complicated relationship between United States (U.S.) public policy and science. It provides evidence of the current U.S. government's attempts to keep climate-related information from the American people, the distortion of facts, and the perversion of federal agencies' missions pertaining to environmental protections. It is not without examples of political leadership and tools to empower the average citizen, however. The purpose of this

[1] Carole LeBlanc is a retired Special Expert for the Department of Defense (DoD), United States Code, Title 5, Part III, Subpart I, Chapter 99, § 9903. In 2007, Dr. LeBlanc was awarded a Defense Special Act Award for her part in the formation of DoD's toxic and hazardous chemicals reduction plan, mandated by Presidential Executive Order 13423. Prior to her 5-year appointment at the Pentagon, she was the Director of the Surface Solutions Laboratory, the research facility of the Toxics Use Reduction Institute (TURI) at the University of Massachusetts Lowell. There, she administered the state's testing program for promoting safer alternatives to hazardous solvents, based on Massachusetts' Toxics Use Reduction Act (TURA) of 1989. She was part of the TURA team that by 1998 had helped to reduce the amount of toxic waste generated in the state by 50%. In 1999, the TURA program would receive the prestigious Ford Foundation Innovations in American Government Award in recognition of this work. Dr. LeBlanc was the first American woman to graduate from Erasmus University's doctoral program in Sustainable Development and Management. Today, she is an Associate Research Faculty member at the University of New England in Biddeford, Maine, U.S. https://www.une.edu/people/carole-ann-leblanc.

paper is to: (1) inform the reader, (2) offer recommendations to citizens based on sound climate science and (3) provide a historical record for future generations interested in ensuring truthfulness and transparency in democracies.

Introduction

This is a difficult chapter to write because to tell the story accurately requires more personal (i.e., first person) language than the author is accustomed to using as a scientist. It involves narrating what it is like to do research on climate change in the present politically-charged national circumstance.

Struggling even with the chapter's title, no matter what my intentions, I would doubtless alienate some readers whose political persuasions might differ from my own. This is ironic, since I have served under U.S. Republican administrations, both at the federal and state levels. In the end, I settled on using the term, 'governance' as opposed to 'government' in the title since:

> "Governance is the act of governing or ruling. It is the set of rules and laws framed by the government that are to be implemented through the representatives of the state. Simply put, governance is what governments do."
>
> Differencebetween.net

The distinction being that the U.S. federal government, like many governments across the globe today, is currently not providing governance in the traditional sense of the word. That is, the framework for *informed* decision-making, at least in some areas, is missing and, in some instances, may be used to mislead the public, as this paper details.

"Weather is what you are wearing; Climate is what you have in your closet."[2]

During the 2018/2019 winter season, the President Trump would often tweet after a bad storm, disparaging his own administration's report on climate change (Fig. 12.1).

[2] Unattributable.

Fig. 12.1 U.S. President Trump's tweet on February 10, 2019 disparaging climate change

While not all of the almost 30,000 retweets may indicate support of the President's claim, the tweet had over 140,000 'likes' in one day. Conflating the two issues of weather and climate is so commonplace that the U.S. National Aeronautics and Space Administration (NASA) has a website dedicated to explaining the difference: https://www.nasa.gov/mission_pages/noaa-/climate/climate_weather.html.

To summarize:

> "Weather is what conditions of the atmosphere are over a short period of time, and climate is how the atmosphere 'behaves' over relatively long periods of time."

These repeated falsehoods by the President of the United States have had the unfortunate effect of mis-informing the American public. Paradoxically, all of the climate change models of which the author is aware include an increase in the number and/or intensity of extreme weather events, like the 'blizzard' he mentions.

In juxtaposition: The U.S. Senate champion for climate action

Sheldon Whitehouse is an American lawyer and politician, serving as the junior U.S. Senator from the state of Rhode Island since 2007. He previously served as a U.S. Attorney from 1993 to 1998 and as the Attorney General of Rhode Island from 1999 to 2003. Whitehouse graduated from Yale University in 1978 and from the University of Virginia School of Law in 1982.

On March 17, 2018, Andrew Freeman[3] wrote:

> "Every week the Senate has been in session since April 2012, one lonely Democratic senator from Rhode Island, Sheldon Whitehouse, has taken to the Senate floor to speak about global warming. On March 13 <2018>, Senator Whitehouse gave his 200th 'It's Time to Wake Up' speech on climate change.
>
> The speech was atypical for Whitehouse, who has grown accustomed to the unsettling feeling of standing virtually alone on the Senate floor while speaking about a topic that he believes is of the utmost importance.
>
> 'It's a very hollow feeling. If you believe that this is a matter of such consequence and that it's going to hit your home state so hard that you are going to put in this kind of an effort, then to have it be in an empty chamber, it's a little disconcerting,' he said in an interview, regarding most of his climate speeches.
>
> This time, though, to mark the anniversary, 19 of his Democratic colleagues joined him to discuss the issue.
>
> Whitehouse's speech was the culmination of years of research and determination on his part, focused on a combination of disturbing new scientific results as well as what he described in an interview as the 'creepy mold growth' of dark money groups spending millions to stop climate action and convince the American public that climate science is uncertain.
>
> 'The fact that stands out for me, here at number 200, is the persistent failure of Congress to even take up the issue of climate change,' Whitehouse said. 'One party won't even talk about it! One party is gagging America's scientists and civil servants, and striking even the term 'climate change' off government websites.'…

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[3] Andrew Freeman is Mashable's Senior Editor for Science and Special Projects. A former Senior Science writer for Climate Central and a reporter for Congressional Quarterly, his writings have appeared in the Washington Post, online at The Weather Channel, and washingtonpost.com in a weekly climate science column. He holds a Master's in Climate and Society from Columbia University, and a Master's in Law and Diplomacy from The Fletcher School at Tufts University.

Whitehouse says he's learned a lot about the science preparing for these speeches, and also has come to investigate why the politics of this issue are so intractable. This has turned his gaze squarely on the Supreme Court's 2010 decision in Citizens United v. FEC <Federal Election Committee>, which allowed for unlimited corporate money and so-called 'dark money' to flow into politics.

'Climate failure and dark money are two sides of the same coin,' Whitehouse said. 'Dark money is flowing to groups that promote the view that climate change is not real, and also punish Republicans that contemplate acting to reduce the severity of the problem.' "…

https://mashable.com/2018/03/17/sheldon-whitehouse-200-climate-change-speeches/#5zI7Zv46Esq

Withholding information: Based on a disdain for science at the leadership level?

During the 2016 U.S. presidential campaign

"Give me a little spray…You know you're not allowed to use hairspray anymore because it affects the ozone, you know that, right? I said, you mean to tell me, 'cause you know hairspray's not like it used to be, it used to be real good… Today you put the hairspray on, it's good for 12 minutes, right…So if I take hairspray and I spray it in my apartment, which is all sealed, you're telling me that affects the ozone layer? 'Yes.' I say no way, folks. No way. No way."

Donald Trump
Campaign rally in Charleston, South Carolina, U.S.
May 5, 2016

This was not the first time that the then-presidential candidate would criticize the ban on chlorofluorocarbons (CFCs) once used as a propellant in aerosol cans. Ostensibly, the comments were made to disparage President Obama for his support of climate-related policies. CFCs were phased out by the Montreal Protocol[4] in 1987, after scientists determined that the chemicals were harmful to earth's ozone layer. The U.S. is a party to this international treaty, whose successful implementation reduced the size of the polar ozone hole.

[4] For an overview of the success of this international treaty see chapter one, *The Montreal Protocol has reinvented itself as a climate protection treaty*, by Drs. Andersen and Sherman in, **Demystifying Climate Risk Volume II: Industry and Infrastructure Implications** (Leblanc, C. ed., Cambridge Scholars Publishing, 2017).

As to the 'sealed apartment' theory: it is the nature of a gas to flow between indoors and outdoors. This is chemistry at the 7th- or 8th-grade level. Otherwise, oxygen (O_2) would not be available for breathing and occupants of any apartment (including the Trump Tower, the author adds facetiously) would be asphyxiated. In 1995, Crutzen, Molina and Rowland won the Nobel Prize in Chemistry for demonstrating how ozone (O_3) forms and decomposes in the atmosphere. Two of these researchers conducted their work in the U.S. They found that CFC molecules, upon gradual transport to the ozone layer, would be cleaved by ultraviolet (UV) light and release chlorine atoms, which decompose ozone. In fact, a single CFC molecule can destroy as many as 100,000 O_3 molecules by a process known as catalysis.[5] The comments reveal a remarkable disdain of science.

After the 2016 U.S. presidential election

In 2017, I was reviewing a paper for a colleague prior to its publication. One of the graphics was not in sharp enough focus for print, so I went online searching for a better, clearer version. The following message appeared across one of the websites in my search results (Fig. 12.2):

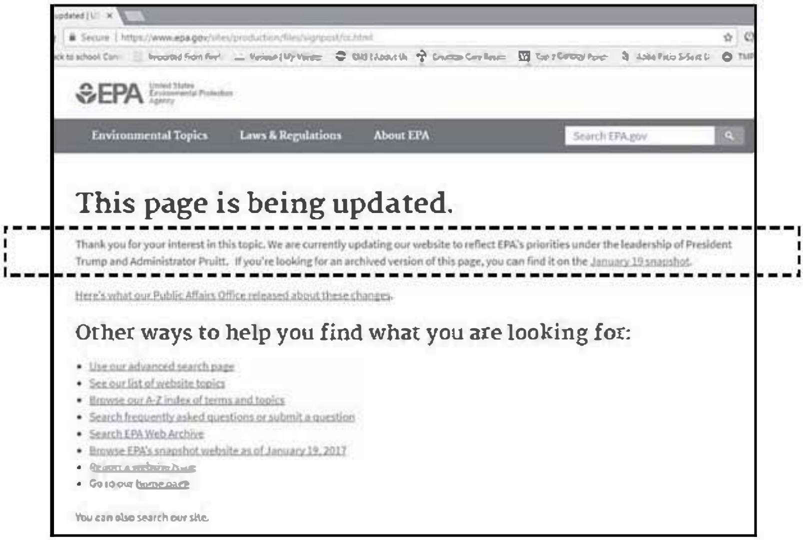

Fig. 12.2. U.S. EPA website with climate change indicators removed in 2017

[5] For more information on the process of catalysis, see chapter four, *Process Improvement in The Pharmaceutical Industry: Using Copper Catalysts* by R. Conger.

I was shocked. I was only looking for the *list* of climate change indicators: obvious things like greenhouse gases (GHGs), weather and climate, etc. No matter where I looked on the U.S. Environmental Protection Agency (EPA) website, I could not find the list. Meanwhile, a colleague at the university where I teach informed me that she had come across the same screen message on a different matter in conducting her own research.

Then, on December 8, 2017, CNN reported that the U.S. EPA had indeed removed references to climate change from its website[6], according to a study conducted by the Environmental Data and Governance Initiative (https://envirodatagov.org/). The report gave examples of before-and-after screen shots of the Agency's websites where the climate-related information had been deleted.

The withholding of scientific information is not just bad for public education and research, it is bad for business. It puts American entrepreneurs at a disadvantage to other competitors in the time-sensitive development of alternative, new technologies.

Prior to his appointment by President Trump as EPA Administrator in February 2017, Scott Pruitt (see bracketed area in Fig. 12.2) had sued the agency over ten times to limit air and water pollution regulations as the state of Oklahoma's Attorney General. His appointment was viewed as Trump making good on the campaign promise to "get rid of" the EPA "in almost every form" and leave it in "little tidbits." Pruitt resigned July 5, 2018 amid unrelated ethics scandals.

Every administration has the right to focus their efforts on what they deem most important to them; that is the consequence of an election. But to reach down so deeply into what citizens (the people who pay for the research), scientists, and non-profit organizations routinely use, and remove that material, is unconscionable. In the over 25 years that I have been doing climate-related work, this had never happened to me before. Whether by design or by oversight, it is unacceptable in a democracy.

The battle for clean air

Besides withholding information from the American people, other attempts have been made to change clean air protections under President Trump's brief tenure thus far:

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6 https://www.cnn.com/2017/12/08/politics/epa-climate-change-references/index.html.

- In December 2017, EPA Administrator Pruitt issued a memo reducing the chances an energy plant will have to abide by stricter air quality standards if it initially miscalculates its future pollutant emissions;[7]
- In January 2018, Pruitt issued a memo repealing a Clinton-era policy known as "once in, always in". The change means industrial facilities deemed "major" sources of air pollution can once again be reclassified as "minor" polluters and avoid tougher clean air regulations;[8] and
- In April 2018, President Trump issued a directive instructing the EPA to work with states having metropolitan areas that fail to attain clean air standards, giving them additional "flexibility" to meet them.[9]

Ostensibly, these changes have been made to reduce regulatory burdens and create jobs. But at what 'costs' and who is 'paying' for them? In November 2018, the U.S. Supreme Court denied the Trump Administration's request for a stay in, Juliana *v* United States, and ruled that a group of young people could, indeed, sue the federal government over its climate change policies.[10,11] Originally filed in 2015, the lawsuit contends that the government encouraged the production of fossil fuels, causing the planet to warm and infringing on several of the plaintiffs' fundamental rights. It lists examples that the government knew the Earth was warming as early as 1965. The lawsuit requests a court order for the government to decrease CO_2 emissions, and create a national plan to "restore Earth's energy balance" and "stabilize the climate system".[12]

> "…these defendants are treating this case, our democracy, and the security of mine and future generations like it's a game. I'm tired of playing this game."
>
> Kelsey Juliana, 22-year-old plaintiff

Or, as the American anthropologist, Margaret Mead (1901-1978) would say:

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7 https://www.epa.gov/sites/production/files/2017-12/documents/nsr_policy_memo.12.7.17.pdf.

8 https://www.epa.gov/newsreleases/reducing-regulatory-burdens-epa-withdraws-once-always-policy-major-sources-under-clean.

9 https://www.whitehouse.gov/briefings-statements/president-donald-j-trump-reducing-barriers-holding-back-american-manufacturers/.

10 https://www.supremecourt.gov/orders/courtorders/110218zr2_8ok0.pdf.

11 https://static1.squarespace.com/static/571d109b04426270152febe0/t/5bdd0596f950b72a53011c0c/1541211544365/2018.11.02+SCOTUS+Decision+x539.pdf.

12 https://static1.squarespace.com/static/571d109b04426270152febe0/t/57a35ac5ebbd1ac03847eece/1470323398409/YoutbAmendedComplaintAgainstUS.pdf.

> "Never doubt that a small group of thoughtful, committed citizens can change the world. Indeed, it is the only thing that ever has."

While some may question the validity of this lawsuit (I am not an attorney), citizens have successfully sued tobacco companies for the harm they caused by lying to customers about the dire health consequences of smoking cigarettes. Most of us are not shareholders of those companies, but we are taxpayers. A democratic government should be held to at least the same standard of truth-telling for the results of publicly-supported research.

Citizen knowledge is power: Provided it is accurate and followed by action

Scholarship

In, *Six Things That Citizens Around the World Urgently Need to Know About Climate Change in Light of Several Recent Scientific Reports*, posted online November 28, 2018,[13] the Scholar in Residence and Professor in Sustainability Ethics and Law at Widener University Commonwealth Law School Harrisburg, Pennsylvania, U.S., divulged:

1. The enormous magnitude of GHG emissions reductions needed to prevent catastrophic warming.
2. The speed of GHG emissions reductions needed to prevent catastrophic warming.
3. No nation may either legally or morally use national self-interest alone as justification for their failure to fully meet their obligation under the UNFCCC <United Nations Framework Convention on Climate Change>.
4. No nation may either legally or morally use scientific uncertainty as justification for their failure to fully meet their obligations under the UNFCCC.
5. Developed countries must legally, morally, and practically more aggressively reduce their GHG emissions than developing countries.
6. Developed countries must legally, morally, and practically help finance mitigation and adaptation programs in poor developing countries."

Dr. Donald Brown[14]

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[13] https://ethicsandclimate.org/2018/11/28/six-things-that-citizens-around-the-world-urgently-need-to-know-about-climate-change-in-light-of-several-recent-scientific-reports/.

[14] Dr. Brown is also a contributing author to the UN IPCC 5th Assessment.

The seminal reports on which Dr. Brown bases his six actionable items for nations include:

- United Nations (UN) Intergovernmental Panel on Climate Change (IPCC) Special Report, *Global Warming of 1.5°C* (October 2018);[15]
- Nature Communications, *21st-century modeled permafrost carbon emissions accelerated by abrupt thaw beneath lake* by K. W. Anthony et al. (August 2018);[1] and
- Proceeding of the National Academy of Sciences of the United States (PNAS), *Trajectories of the Earth System in the Anthropocene*[16] by W. Steffin et al. (July 2018).

These and other recent scientific reports on climate change:

> "…lead to the conclusion that the international community is facing an urgent existential crisis that threatens life on Earth. Preventing this catastrophe requires the entire international community at all levels of government (national, state, regional, and local) to engage immediately in an unprecedented effort to rapidly reduce GHG emissions to net zero in the next few decades."[2]

Tragically, those countries emitting the least amount of GHGs are the most impacted by climate change.[3] In fact, as early as 2008, the UN warned about the impact of climate change on conflicts and refugees.[4]

Anatomy of 'real' fake news

But sound, scientific information is not always easy for the public to distinguish from other sources of information. Reporters can also fall prey to inaccuracies, if they do not follow through to their sources. Take the unjustified discrediting of the International Agency for Research on Cancer:

> "STEP 1: Monsanto feeds a deposition of scientist Aaron Blair to a Reuters reporter, and accuses the scientist of deliberately concealing key data from International Agency for Research on Cancer (IARC).[17]

[15] https://www.ipcc.ch/sr15/.

[16] The Anthropocene is the current geological epoch or age in which human activity has had a dominant influence on the environment beginning, some geologists would say, with the Industrial Revolution.

[17] For more information on IARC, see chapter three, *Pollution Prevention Options Analysis System*, by J. Marshall.

STEP 2: Reuters publishes story stating that in Blair's deposition, Blair said the data would have altered IARC's analysis. The reporter wrote: He said it would have made it less likely that glyphosate would meet the agency's criteria for being classed as 'probably carcinogenic.' Nowhere in the deposition does Blair say this, but Reuters failed to provide a link to the deposition, and quoted Monsanto saying the failure undermined IARC's classification of glyphosate. In addition to quoting Monsanto, Reuters quotes a scientist who has been paid to consult with Monsanto as saying IARC work was 'flawed'.

STEP 3: Same day Reuters story comes out American Chemistry Council issues press release promoting the Reuters story, falsely saying Blair 'deliberately withheld research which he admits likely would have altered the cancer agency's analysis.' Chemistry group says 'fundamental reform' of IARC is needed. Other chemical industry groups repeat the false accusations, linking to each other's posts, and spreading narrative that Blair said the withheld data would have altered the classification, which he did not say.

STEP 4: Mother Jones magazine and other media outlets repeat allegations in Reuters story, also without linking to actual Blair deposition, giving readers no ability to see the true statements by Blair.

STEP 5: Chemical industry lobbies Congress to investigate IARC, quoting from the Reuters story and false statements attributed to Blair. Rep Lamar Smith takes up the cause and is now threatening to strip funding from IARC.[18] Tentative hearing <was> planned for Feb. 6, 2018."

Carey Gillam[19]

'Spin' on steroids: When does an exaggeration become a lie?

To build acceptance of any policy, it is necessary to put the best public face on it; that is understandable and commonplace. Most often, whether a policy is eventually enacted, comes down to the fiscal cost of its implementation; that is also understandable.

However, cost-benefit analyses can ignore or discount very real societal costs to, for example, public health (increased rates of asthma, related

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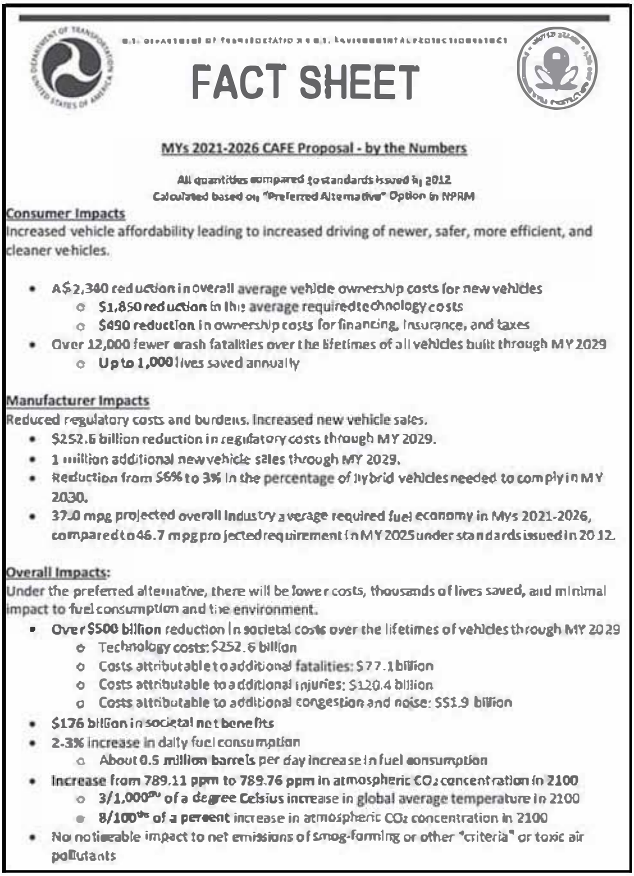
18 https://thehill.com/policy/energy-environment/372517-gop-chairman-questions-us-funding-for-international-chemical.

19 Investigative reporter Gillam was the Society of Environmental Journalists 1st Place Winner of the Rachel Carson Environment Book Award in 2018 for, *White Wash: The Story of a Weed Killer, Cancer and the Corruption of Science*. Rachel Carson (1907-1964) was perhaps the best nature writer of the 20th century and author of *Silent Spring* (1962), which warned about the dangers of chemicals like the pesticide, DDT. http://www.rachelcarson.org/.

emergency room visits, etc.), depending on who is conducting the analysis, and to what end. The author considers the Trump Administration's rollback of Obama-era projected fuel efficiencies to be under false pretenses (Fig. 12.3).[20]



FACT SHEET

MYs 2021-2026 CAFE Proposal - by the Numbers

All quantities compared to standards issued in 2012
Calculated based on "Preferred Alternative" Option in NPRM

Consumer Impacts
Increased vehicle affordability leading to increased driving of newer, safer, more efficient, and cleaner vehicles.

- A $2,340 reduction in overall average vehicle ownership costs for new vehicles
    - $1,850 reduction in the average required technology costs
    - $490 reduction in ownership costs for financing, insurance, and taxes
- Over 12,000 fewer crash fatalities over the lifetimes of all vehicles built through MY 2029
    - Up to 1,000 lives saved annually

Manufacturer Impacts
Reduced regulatory costs and burdens. Increased new vehicle sales.

- $252.6 billion reduction in regulatory costs through MY 2029.
- 1 million additional new vehicle sales through MY 2029.
- Reduction from 56% to 3% in the percentage of hybrid vehicles needed to comply in MY 2030.
- 37.0 mpg projected overall industry average required fuel economy in MYs 2021-2026, compared to 46.7 mpg projected requirement in MY 2025 under standards issued in 2012.

Overall Impacts:
Under the preferred alternative, there will be lower costs, thousands of lives saved, and minimal impact to fuel consumption and the environment.

- Over $500 billion reduction in societal costs over the lifetimes of vehicles through MY 2029
    - Technology costs: $252.6 billion
    - Costs attributable to additional fatalities: $77.1 billion
    - Costs attributable to additional injuries: $120.4 billion
    - Costs attributable to additional congestion and noise: $51.9 billion
- $176 billion in societal net benefits
- 2-3% increase in daily fuel consumption
    - About 0.5 million barrels per day increase in fuel consumption
- Increase from 789.11 ppm to 789.76 ppm in atmospheric CO_2 concentration in 2100
    - 3/1,000th of a degree Celsius increase in global average temperature in 2100
    - 8/100ths of a percent increase in atmospheric CO_2 concentration in 2100
- No noticeable impact to net emissions of smog-forming or other "criteria" or toxic air pollutants

Fig. 12.3 The Trump Administration's proposed new rule for Corporate Average Fuel Economy (CAFE) standards for model years (MY) 2021-2026

[20] https://www.nhtsa.gov/sites/nhtsa.dot.gov/files/documents/rev_fact_sheet_cafe_nprm_by_the_numbers_003-tag.pdf.

Major concerns include:

- The document is entitled a 'fact sheet' (in capital letters). Yet, it begins with the assumption that more cars will be purchased under the new (i.e., lower) gas mileage target;
- Virtually all data points listed thereafter are dependent on that assumption;
- The document correctly uses the logos of the Department of Transportation and the Environmental Protection Agency under which the rule was written. My greatest fear is that as all of the facts upon the new rule's implementation emerge, the public's trust in government institutions will be further eroded; and
- It downplays the new rule's impact on GHG emissions (Fig. 12.4).

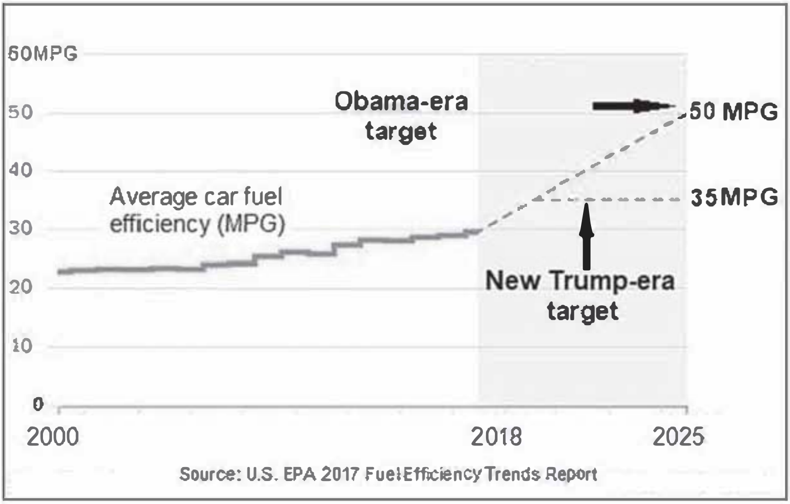


Fig. 12.4 Comparison of Obama-era and Trump-era fuel efficiencies in miles per gallon (mpg)

The results of the new Trump-era target are expected to be:

- An increase in fuel consumption by approximately 500,000 barrels of oil per day (an increase of up to 3%);
- Leading to an *increase* in GHG emissions at exactly the same time we should be significantly *decreasing* GHG emissions.

Interestingly, not all car manufacturers are in complete support of the new rule. Based on my experience with the automotive industry, this may be due, at least in part, to the necessary investments in production and manufacturing design that had already begun in preparation for the Obama-era target. Basically, the government's proposed lower, gas mileage target will punish these companies for doing the right thing, putting them potentially at a competitive disadvantage.

Not all states, especially California, are expected to agree to the new rule.

Recommendations for citizens

"Concerned citizens need to mount an aggressive educational program to inform civil society about aspects of the climate change threat that appear to be poorly understood."

Dr. Donald Brown[2]

Proposed: Ten principles of climate action for citizen advocates

Only by working together can advocates of sound, science-based public policy for climate change prevail in the U.S. against the political power wielded by groups like Citizens United[21]. Consequently, the author developed the following *ten principles of climate action for citizen advocates*, based upon her years of work in the field and the latest climate science detailed in this and the previous two books on climate risk (Table 12.1):

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[21] In 2010, the U.S. Supreme Court voted 5-4 in favor of Citizens United *v* the Federal Election Commission. The decision extended "free speech" rights, usually associated with individuals with regard to voting, to groups like corporations. Sixteen states and more than 680 cities and municipalities have called on the U.S. Congress to pass a constitutional amendment to overturn the decision. In 2014, an attempt to do so, the *Democracy For All* amendment failed in the Senate. See also, U.S. Senator Whitehouse' comments on the court's Citizen United decision and its impact on climate change policy earlier in this chapter.

Table 12.1 Ten principles of climate action for citizen advocates

1. **Join forces with a group**. Some organizations maype part of, or have alliances with, national/international associations. Find the one that best speaks to your own personal interests, for example, habitat protection (Table 12.2). While emails, newsletters, etc., will keep you updated, do not overdue this by joining several groups; otherwise, you can quickly become overwhelmed.
2. **Reward companies that practice environmental stewardship[22] with your business**. Remember that not all commercial labels, and names of companies, reflect much more than a sales pitch. Organizations like the U.S. Environmental Protection Agency (EPA) Design for the Environment (DfE) program, and the non-profit Green Seal, can help you make better informed purchasing decisions. You can find these and other product labels at: http://www.ecolabelindex.com/.
3. **Practice what you preach by reducing your plastic consumption**. Immediately stop using bottled water (it is not always demonstrable that bottled water is healthier to drink), and single-use plastic bags (it takes 12 million barrels of oil to produce the amount of plastic bags the U.S. uses every year, and most recycling facilities cannot accept them). Support policies to dissuade the use of plastic bags.[23]
4. **Volunteer in climate change action**. Many environmental and voting rights groups are always looking for, and very grateful for, all kinds of help (see Table 12.2).
5. **If you are working outside of the home, find out if your company has a position or interest in climate change**. Sometimes, all it takes is for one employee to express a genuine and sincere concern for management to consider involvement. Environmental engagement is considered a ‘plus’ for many customers and, therefore, a competitive advantage for some firms (see Principle 2).

[22] “Environmental stewardship is the responsibility for environmental quality shared by all those whose actions affect the environment.” U.S. EPA

[23] Ireland was the first European country to tax plastic bags, decreasing their consumption by 90% and removing 1.08 billion bags from the waste stream since 2002. The tax generated $9.6 million for a green fund to support environmental projects. http://www.irishenvironment.com/iepedia/plastic-bag-levy/

6. **If this book has peaked your interest to learn more about climate change, take a course at a local university, community college, or online**. If none is available in your area, suggest that your school consider adding one to its curriculum.
7. **If you have children in your care, work to ensure that their education includes how important a healthy climate is**. It is not too early to introduce these concepts, at the appropriate level, in grammar school.
8. **Consider a career in, or a career change to, a climate-related discipline**. Engineers and chemists are not the only professionals that are needed now and in the years to come; environment, health, and safety (EHS) specialists, communications experts, entrepreneurs, etc., are also needed. For some ideas, see: (1) CERES, "a sustainability nonprofit organization working with the most influential investors and companies to build leadership and drive solutions throughout the economy", at https://www.ceres.org/ and (2) ACCO, the Association for Climate Change Officers, at https://climateofficers.org/. Perhaps attend one of their meetings.
9. **If you are a person of faith, determine if your religious community has a position on climate change to show respect, care, and gratitude for creation**. Ask that they consider ecumenical efforts with other faith groups. For a list of religious communities that have released statements on climate change, see: https://www.interfaithpowerandlight.org/religious-statements-on-climate-change/.[24]
10. **VOTE in every election**. Local representation is very important to climate change issues (for example, land management). Right now, make sure you are registered to vote and if you need help, visit: https://vote.gov/ (in the U.S.). If you need help on how/where to vote, visit: https://www.usa.gov/election-day (in the U.S.). If you do not have a computer, or you are not computer literate, your local library may be able to help. Before you vote, make sure you understand the issues (ballot questions, etc.) and the positions on climate change of *all* of the candidates.

[24] For instance, see the statement from the Evangelical Lutheran Church in America on the 2018 IPCC Report and Caring for Creation at: https://download.elca.org/ELCA%20Resource%20Repository/Environment_IPCC_Report_Resource_1811v2.pdf.

Table 12.2 Some organizations and environmental groups involved with climate change

in alphabetical order

Name	Website	Phone (U.S.)
1. 350.org	https://350.org/	646-801-0759
2. Audubon Society	http://climate.audubon.org/	844-428-3826
3. Common Cause	https://www.commoncause.org/	202-833-1200
4. Environmental Defense Fund	https://www.edf.org/	800-684-3322
5. Greenpeace	https://www.greenpeace.org/	202-462-1177
6. League of Conservation Voters	https://www.lcv.org/	202-785-8683
7. League of Women Voters	https://www.lwv.org/	202-429-1965
8. Natural Resources Defense Council	https://www.nrdc.org/	212-727-2700
9. Nature Conservancy	https://www.nature.org/	703-841-5300
10. Public Citizen	https://www.citizen.org/	202-588-1000
11. Rocky Mountain Institute	https://www.rmi.org/	303-245-1003
12. Sierra Club	https://www.sierraclub.org/home	415-977-5500
13. Union of Concerned Scientists	https://www.ucsusa.org/	617-547-5552

Another citizen tool: The Freedom of Information Act[25]

In a political era when accurate, scientific data may be harder to come by, a powerful tool for citizen advocates is the Freedom of Information Act (FOIA). Signed by U.S. President Lyndon Johnson and enacted in 1966, the act generally provides (some exclusions apply, such as those issues pertaining to national security) that:

- Any person has the right to request access to federal agency records or information; and
- All agencies of the U.S. government are required to disclose records *upon receiving a written request for them*. <emphasis add>

FOIA searches undertaken by the government are usually conducted within a certain timeframe and may involve a cost. Nonetheless, as a former federal employee who participated in such searches on behalf of an agency, I can

25 https://www.foia.gov/how-to.html.

tell you that FOIA responses must be as thorough as possible, and include email searches for the key words provided in the request. Some state governments have their own versions of FOIA.[26]

Concluding remarks

From 2010-2011, the author was honored to represent the U.S. Department of Defense (DoD) as a member of the Nanotechnology Environmental and Health Implications (NEHI) Working Group and a contributor to the human health section of the National Nanotechnology Initiative (NNI) Environmental, Health, and Safety Research Strategy (Fig. 12.5).[27]

The publication of this +125-page document required the cooperation of dozens of federal agencies, each with its own legitimate perspective and agenda. But each of us were honest brokers; that is, all of the representatives understood and respected that it was our job to look after the individual missions of each of our respective agencies.

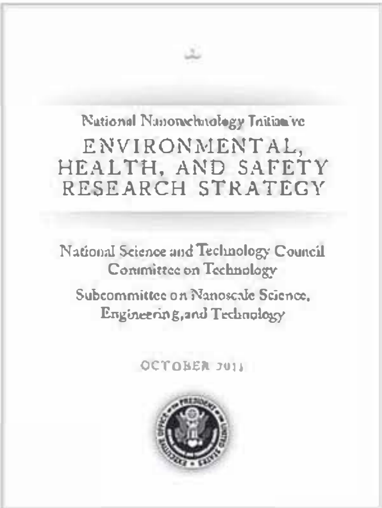

Fig. 12.5 The 2011 U.S. NNI Environmental, Health, and Safety Research Strategy, an example of federal agency cooperation

[26] For example, the state of Maine: https://www.maine.gov/foaa/.
[27] https://www.nano.gov/sites/default/files/pub_resource/nni_2011_ehs_research_strategy.pdf

Now, imagine what would have happened if I had been asked to represent the interests of the EPA while serving at the DoD. Neither agency would have been served well, and all trust would have been lost in the process.

That is exactly what has happened with nominations and appointments in the Trump Administration, most notably at the EPA under Scott Pruitt with glaring conflicts of interest, as mentioned in this chapter, and at the Department of the Interior under Ryan Zinke[28]. These executive decisions make a mockery of the intended functions of important government institutions.

This chapter has focused on only a few of the highlights of the Trump Administration's efforts to unravel years of progress in environmental safeguards. But there is some good news. While President Trump has often repeated that he has pulled the U.S. out of the Paris Agreement[29], the truth is:

> "By coincidence or design, the process of withdrawal can only begin the day after the 2020 U.S. presidential elections."[5]

Make no mistake about it: this is a fight. It is a fight that, along with hundreds of thousands of others, I will continue to wage. Not for myself – this country has been very good to me – but for the student who, one day in the Fall semester of 2018, waited after class to thank me for how much she had learned with a note containing a gift card to Dunkin' Donuts (which I treasure so much, I may never use). It is for this young woman's future that we persevere.

Acknowledgements

The views expressed in this chapter are entirely the author's.

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[28] Refer to the Preface for information on Mr. Zinke's brief tenure.

[29] In December 2015, Parties to the UNFCCC reached consensus on The Paris Agreement. Its central aim is to strengthen the global response to the threat of climate change by keeping a global temperature rise this century well below 2° Celsius (C) above pre-industrial levels and to pursue efforts to limit the temperature increase even further to 1.5°C.
https://unfccc.int/sites/default/files/english_paris_agreement.pdf.

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CONCLUSION

As a Jesuit[1]-trained scientist, I have known for most of my professional life that the Catholic Church has played a major role in the history and development of the modern scientific method[2], dating back to the Middle Ages. Robert Grosseteste, Albert the Great, Roger Bacon, and Thomas Aquinas are all part of that proud tradition. So for me, there has never been a crisis between my faith and the practice of my profession. Stated plainly: deliberate ignorance does not glorify God; if the Almighty gave you a brain, he most assuredly expects you to use it.

Jesuit training at Boston College[3] also provided me with an understanding that *authentic leadership requires service*. This conviction was further substantiated during my tenure at the Pentagon, where so many people have chosen to serve and to sacrifice.

To wit, at the annual 'Al Smith'[4] dinner in New York City on October 28, 2018, the United States (U.S.) Ambassador to the United Nations (UN) said that she had been to some "truly dark places", where the suffering endured by many people would be:

> "…hard for most Americans to imagine. I've been to the border between Colombia and Venezuela, where people walk 3 hours each way in the blazing sun to get the only meal that they will have that day. Who's giving that meal? The Catholic Church. I've been to refugee camps in Central Africa where young boys are kidnapped and forced to become child soldiers and young girls are raped as a matter of routine. Who was in the forefront of changing this culture of corruption and violence? The Catholic Church."
>
> UN Ambassador Nikki Haley

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[1] Term used to describe members of the Society of Jesus, an order of Catholic priests founded in 16th century Spain by Ignatius of Loyola. The Jesuits are known for their work in education, intellectual research, and cultural pursuits throughout the world.
[2] The systematic observation, experimentation, and measurement to test an hypothesis (proposed explanation) following the identification of a problem, condition, etc.
[3] Founded in 1863 by the Jesuits, Boston College (BC) is located in Chestnut Hill, Massachusetts, U.S. BC's original mission was to educate the city of Boston's predominantly Irish Catholic immigrant community.
[4] Al Smith was an American politician elected governor of New York state four times and the first Catholic candidate for the U.S. presidency in 1928.

What has this got to do with climate change? *If* we, as a society, decide to address climate change successfully, it will undoubtedly involve both (1) hard work and (2) personal sacrifice. This is not an effort to proselytize, but rather to help make the connection between our morals and our actions clearer. In other words, *service to others can and should be joyous*! How else can we possibly hope to heal the climate risks and disparities that exist around the world.

In 2006, the Catholic Climate Covenant was founded based on, *Global Climate Change: A Plea for Dialogue, Prudence, and the Common Good*, the 2001 statement of the U.S. Conference of Bishops. The covenant:

> "inspires and equips people and institutions to care for creation and care for the poor."
>
> https://catholicclimatecovenant.org/about/story

The 2015 papal encyclical, *Laudato Si' (Praise Be to You): On Care for Our Common Home* begins with a quote from the *Canticle of the Creatures* by Saint Francis of Assisi, Italy (née Giovanni di Pietro di Bernardone 1181/1182–1226), founder of the Franciscan religious order.

The canticle is a hymn of praise which, according to Saint Francis, summarizes the journey to God in and through the beautiful things of creation manifesting God's goodness. *It was composed one year before his death, while laying ill in a small, dark hut.* The canticle reminds us that humans are as dependent on the elements of creation as they are dependent on us as their stewards. With his endearing respect for creatures of all kinds, for sun, moon, stars, water, wind, fire, and earth, Francis refers to them in human-family terms: mother, brother, sister.

The encyclical's plea is:

> "The urgent challenge to protect our common home includes a concern to bring the whole human family together to seek a sustainable and integral development, for *we know that things can change* <emphasis added>"
>
> Pope Francis I

How remarkably similar to the final public sentiments of U.S. Senator John McCain recounted in the Preface.

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EPILOGUE

Within months of my arrival at the United States (U.S.) Department of Defense (DoD) in 2007, I was asked to put together a paper on the department's readiness for 'REACH', the European Union (EU) *Registration, Evaluation, Authorisation, and Restriction of Chemical Substances*[1]. Enacted in 2006, REACH addresses the production and use of chemical substances, and their potential impacts on human health and the environment in the +25 member-state union.

DoD uses many products that the department does not manufacture, and are obtained instead via commercial supply chains. Moreover, our forces are stationed all over the world, including Europe. The products and components bought and used by DoD still need to function properly in extreme conditions (for example, components in a conflict area *vs* a company office). The concern was that some newer alternatives, albeit safer and greener, may not perform at the level DoD required.

When I was given a draft of the response regarding REACH from another DoD office, I was more than a little surprised. Basically, the draft stated that the department *was* prepared, but I knew that was not exactly the case. A previous EU directive, ROHS, the *Restriction of Hazardous Substances*[2] had made it difficult for the department to easily identify the contents of electrical and electronic equipment in defense supply chains, pre- and post-passage of this law. Both REACH and ROHS are based on the application of the *precautionary principle*[3].

Asking why the paper was somewhat less than straightforward, I was told: because that's what they <management> wanted to hear (I am paraphrasing). These were good, hard-working people who really thought that telling the boss what s/he wanted to hear was part of their jobs. This kind of misplaced loyalty at DoD is somewhat understandable, given that

[1] The text of the original +800-page REACH regulation is available at: https://eur-lex.europa.eu/legal-content/EN/TXT/PDF/?uri=CELEX:32006R1907&from=EN.

[2] The text of the original ROHS directive is available at: https://eur-lex.europa.eu/LexUriServ/LexUriServ.do?uri=OJ:L:2003:037:0019:0023:EN:PDF.

[3] The chief characteristic of the principle is risk prevention in the face of scientific uncertainty, aiming to prevent harm *before* a hazard exists. Consider also the medical edict, *primum non nocere* (Latin for "first do no harm").

the department necessarily practices a form of hierarchical governance, where following orders can mean the difference between life and death. It is a culture prevalent not only in government, but in business as well.

I am grateful and proud that the department allowed me to re-write the document, and the Secretary of Defense had the information he needed to help reduce risks and better protect defense supply chains.

Here, then, is the moral of the story:

After years of working in what still amounts to a man's field (e.g., chemical engineering), I am struck by the different ways men and women solve problems, which I view as a good thing. This may be anecdotal, and I am not speaking as a scientist, but men appear to me to be far more competitive, obtaining much more of their identity/ego from their jobs. Women, on the other hand, appear to me to be more inclined to network, not caring as much, perhaps, on who gets credit for solving the problem (or the blame for telling the truth!); just as long as the problem gets solved. Could this be the result of years of settling family disputes? I really do not know.

As a Catholic, I believe that the child sexual abuse scandal involving priests, who are all men, will not be fully resolved unless or until women are granted positions of greater authority in the church. Likewise, *I am equally convinced that the representation of democratic governments needs to be proportionate to their male/female, white/black, etc., populations. Only then will a society's real problems be identified and solved.*

U.S. presidents face the same situation with their White House staffs, and President Trump is no exception. Without a diverse staff and the ability and courage to tell the Commander-in-Chief the truth without retribution, actual problems will not be identified, and others will only worsen. It is the responsibility of the executive to promote a culture in which s/he can hear and accept facts as they are revealed, and act on them for the betterment of the country. Case in point: the real and present danger of the climate crisis left unabated by the lack of a cohesive, U.S. federal policy to date.

In the next book, I hope to address the existential threat of climate change with specific policy recommendations to dramatically, rapidly, and responsibly reduce greenhouse gas (GHG) emissions. These proposals for governments will be postulated in much the same way, but in greater detail, as the *Ten Principles of Climate Action for Citizen Advocates* presented in chapter twelve, *The Role of Ethics and Governance in the Pursuit of Climate Science.*

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