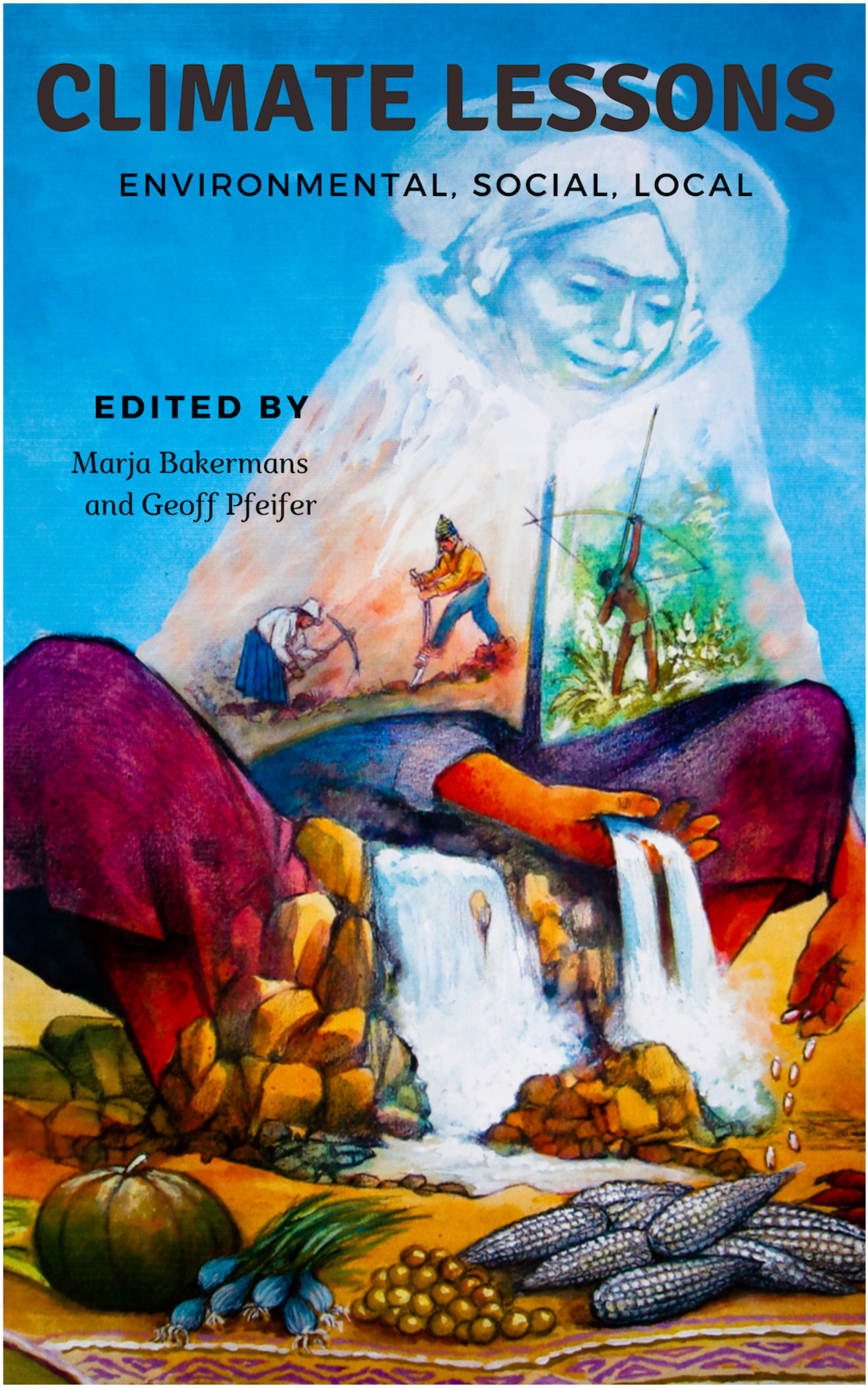
CLIMATE LESSONS

ENVIRONMENTAL, SOCIAL, LOCAL



EDITED BY

Marja Bakermans
and Geoff Pfeifer

Climate Lessons

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Environmental, Social, Local

MARJA BAKERMANS

WORCESTER POLYTECHNIC INSTITUTE
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Contents

Copyright ix

Gratitude x
Marja Bakermans

The Topic and the Text 1
Marja Bakermans

Part I. Climate Systems

1. Atmosphere 5
By Elizabeth Dalberg, Katherine Miller, and Nora Smith
2. Hydrosphere 17
By Isabella Cloves, Katherine Corbin, and Frank Ford
3. Cryosphere and Lithosphere 25
By Keelan Boyle, Jack Hanlon, Alexander Wadsworth, and Gabriel Ward
4. Biosphere 37
By Gabriel Espinosa and Daniel Shea

Part II. Social Impacts of Climate Change

5. Climate Change Impacts on Food Systems 51
By Keelan Boyle, Isabella Clowes, and Katharine Miller

6. The Societal Impacts of Climate Change on Water Resources 66

By Katherine Corbin, Elizabeth Dalberg, and Gabriel Ward

7. Climate Change Impacts on Human Health 75

By Gabriel Espinosa, Frank Ford, and Alex Wadsworth

8. Inequalities Due to Climate Change 86

By Jack Hanlon, Daniel Shea, Nora Smith

Part III. Communities and Climate Change

9. Puerto Rico 101

By Keelan Boyle, Katherine Corbin, and Daniel Shea

10. Boston 115

By Elizabeth Dahlberg, Gabriel Espinosa, and Jack Hanlon

11. The Himalayas 127

By Isabella Clowes, Nora Smith, and Alexander Wadsworth

12. Fiji 138

By Frank Ford, Katharine Miller, and Gabe Ward

Part IV. In Search of Solutions

13. Rigged for Oil Rigs 151

By Katherine Corbin, Nora Smith, and Gabriel Ward

14. Climate Change Impacts on Native Hawaiian Population 165

by Isabella Clowes, Elizabeth Dahlberg, and Katharine Miller

15. Destigmatizing Nuclear Energy to Decarbonize the Worlds' Power Supply 183

By Keelan Boyle, Frank Ford, and Daniel Shea

16. Small Scale Carbon Capture Implementation and Utilization 203

By Gabriel Espinosa, Jack Hanlon, and Alexander Wadsworth

Appendix 225

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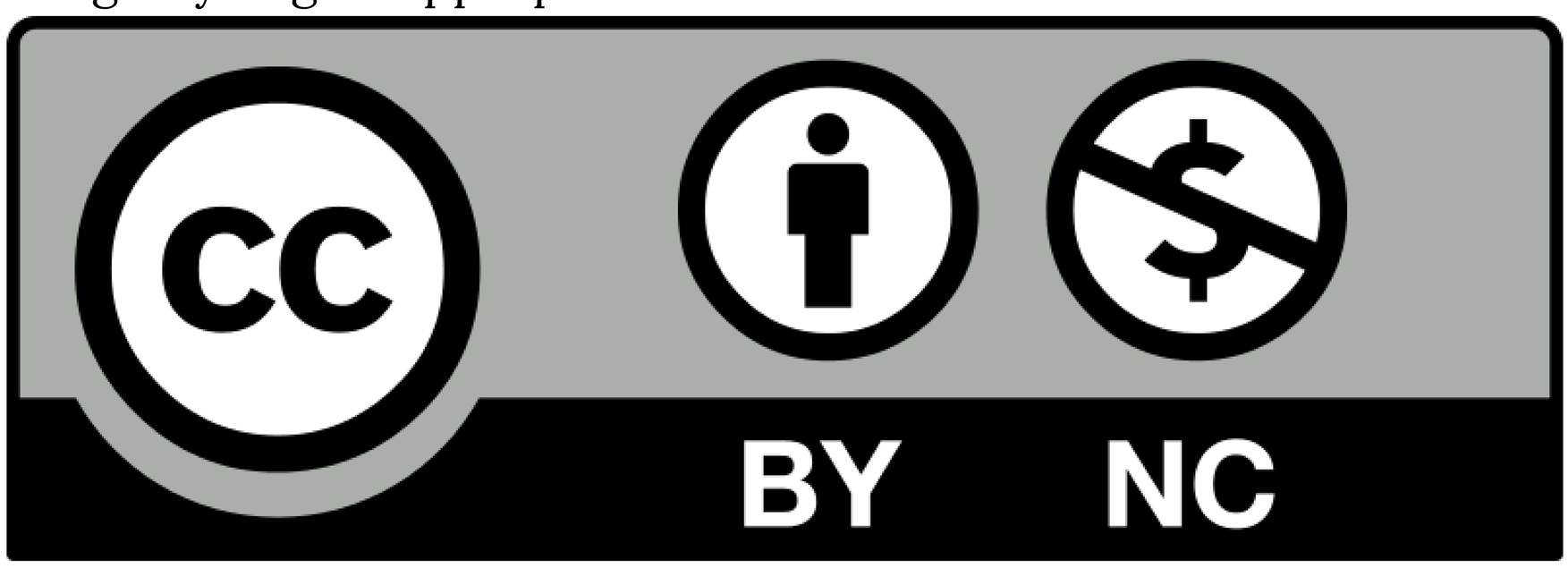

Gratitude

MARJA BAKERMANS

Words of gratitude from the course instructors:

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We are beyond thankful to Elaine Chen, a talented, insightful, and gracious Peer Learning Assistant. Elaine provided mentorship, leadership, and advice to students in the course that is absolutely invaluable.

The students are the real stars of this text. We thank you for your hard work and passion in diving into tough topics- and all of this during a global pandemic. Thank you for bringing us on this journey with you and we cannot wait to see what you do in the future!

The Topic and the Text

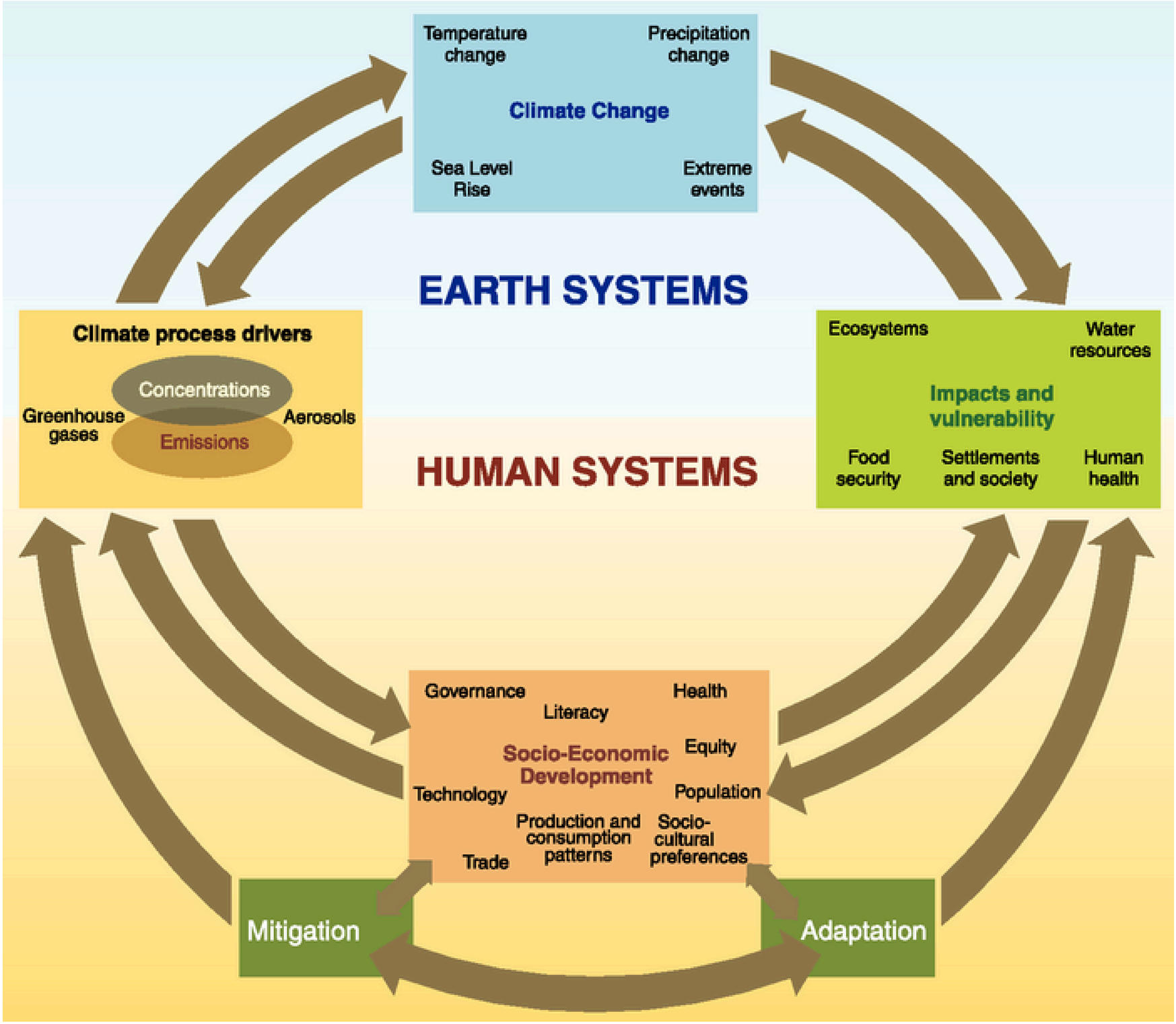
MARJA BAKERMANS

Anthropogenic climate change is one of the, if not the most, pressing issues of our times. The problems that it causes range across many social and environmental domains from habitat and species loss and displacement to the more human and social concerns and issues of access to water, sea level rise that affects coastal communities, to economic degradation as a result of the aforementioned and other connected issues such as increased frequency of storms, droughts, wildfires, and the like. We also know that the affects of climate change are not distributed evenly across populations- that many will and do feel the negative effects of this slow developing problem earlier and more intensely than others based on where they are located both geographically and within economic and other socio-cultural hierarchies.

We also know that recently, there is a marked effort to begin to move away from simply decrying the horrors of climate change to a continued recognition of those horrors as they exist now and into the future alongside attempts to begin to come to terms with the changing climate and to rethink the ways that our social and environmental relations and communities are organized with an eye toward both adapting to these changes and mitigating further damage. There is, however, much work to be done.

This book was co-authored by undergraduate students at Worcester Polytechnic Institute while exploring the influences of Earth systems and human systems on climate change and the communities at most risk in an interdisciplinary project-based first year course (Fig 1 below). This course attempts to bring together knowledge of the science of ecological and climate systems and their changing status with knowledge of the social and communal structures within which these systems are embedded and through which they have been influenced. The book highlights key interests

and insights of current students in their quest to think through these issues and to create a better world.



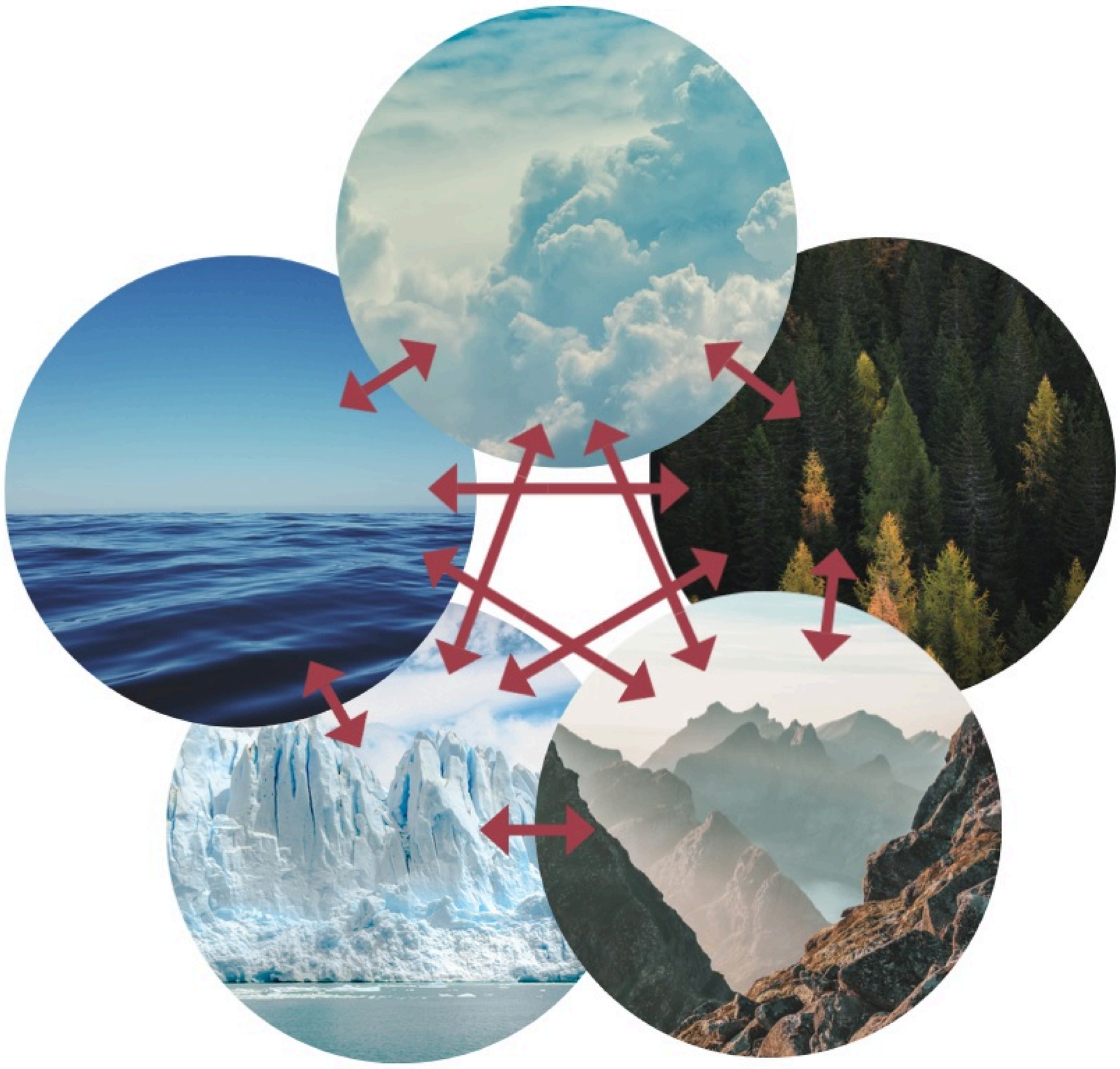
The work in this book was framed using the Intergovernmental Panel on Climate Change (IPCC) framework of climate change drivers, impacts and responses, where section 1 focuses on Earth Systems, section 2 on human systems, and sections 3 and 4 on community and research topics that explicitly consider both Earth and human systems. "Schematic framework of anthropogenic climate change drivers, impacts and responses", IPCC Fourth Assessment Report: Climate Change 2007, Courtesy of IPCC.

PART I

CLIMATE SYSTEMS

In this set of chapters, students researched and the planetary systems that shape climate and are involved in global climate change. In doing so, they explain the climate system, including its components and composition and use key climate indicators to illustrate how changes are occurring in the system. Next, they identify drivers or causes of change in climate systems, and explain how we know these systems and their indicators are changing. Finally, teams of students then explore the social and environmental systems threatened by or benefit from changes in climate systems.

Chapter 1 explores the atmosphere and focuses on changes in greenhouse gases since the Industrial Revolution. Chapter 2 researches the hydrosphere, with a special examination of the physical changes of Lake Baikal in Siberia and the resulting biological consequences. Two climate systems, the cryosphere and lithosphere, are explained in Chapter 3, with a focus on how the systems interact together. Finally, the biosphere is explained in Chapter 4, with key highlights of how ecosystems and wildlife communities are adapting (or not) to climate change. When learning about these systems, note that all Earth systems interact (see Figure below) so at times it is difficult to separate these systems. Students, in their writing, highlight how these complexities make understanding and predicting future changes more difficult.



The Earth's five climate systems, from top and moving clockwise: atmosphere, biosphere, litosphere, cryosphere, and hydrosphere. "The five components of the climate system all interact." by Femkemilene, CC BY-SA 4.0

1. Atmosphere

By Elizabeth Dalberg, Katherine Miller, and Nora Smith

Abstract

The atmosphere, which is primarily composed of nitrogen and oxygen, is one of the most influential climate systems on Earth. As the concentration of certain key gases in the atmosphere has shifted over time, the importance of the atmosphere has become more apparent. These small shifts in gases like CO_2 and methane have significantly worsened the greenhouse effect and have led to some major changes in Earth's climate. Some major consequences of this shift have been the increased melting of sea ice, increased ocean acidity, worsening of natural disasters like hurricanes and wildfires, and the reduction of air quality in heavily populated areas. How and why has such a small shift in atmospheric concentration been able to cause so much devastation and how will it continue to do so?

The Atmosphere

The atmosphere is the climate system made up of the gas layer that surrounds our planet, which primarily contains oxygen, nitrogen,

argon, carbon dioxide, helium, and neon (Boudreau et al., 2011; Figure 1).

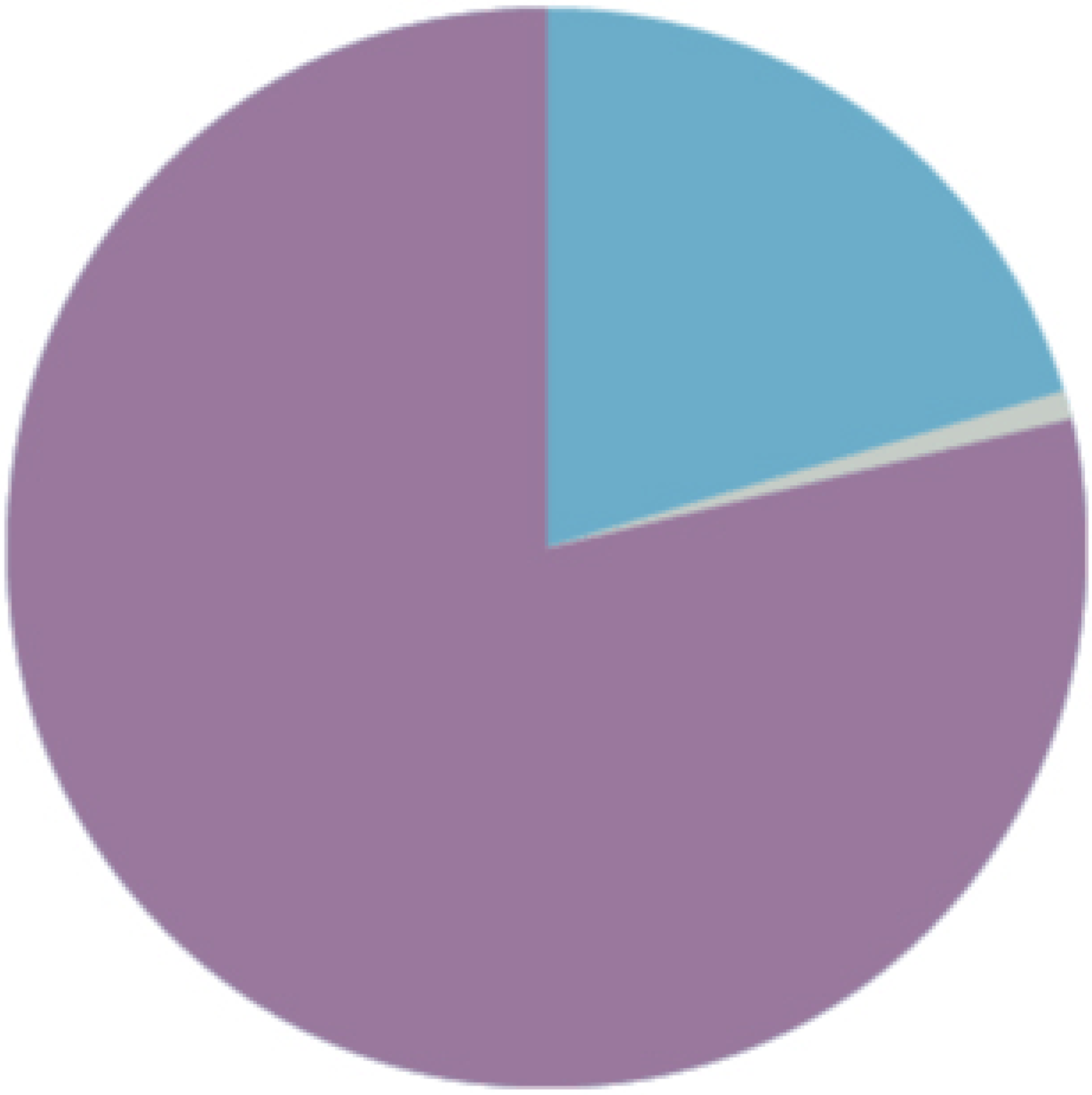


Figure 1: Percentage of gases in Earth's atmosphere. Credit: chapter authors

The atmospheric concentration of gases present in today's atmosphere is a direct result of Earth's history. Scientists believe that much of the nitrogen and many trace gases in our atmosphere is the result of early volcanic eruptions; furthermore, it is hypothesized that free oxygen (O_2) was mainly created by early organisms during photosynthesis (Boudreau et al., 2011). The atmosphere shields Earth from much of the Sun's UV radiation, which is harmful to humans in large amounts, while allowing most

of the Sun's rays and solar heat to pass through. When the solar heat and Sun's rays pass through the atmosphere, it traps water vapor in the atmosphere. Water vapor (an important natural greenhouse gas) warms the Earth and keeps it habitable for plants and animals (Buis, 2019).

The layers of the atmosphere are the troposphere, stratosphere, mesosphere, thermosphere, and exosphere (Boudreau et al., 2011; Figure 2). The troposphere, the closest layer to the surface, holds water vapor and develops the weather, while the stratosphere contains the ozone which shields Earth from UV radiation. The mesosphere is where we see shooting stars, but is the least known component of the atmosphere. The ionosphere holds radio waves and displays the Northern and Southern Light auroras. Next is the thermosphere, which holds oxygen, helium, and hydrogen gas that absorb X-ray and UV radiation. Lastly, we have the exosphere, where solar storms happen and where weather satellites orbit. All of Earth's atmospheric layers play an important role in understanding climate change.

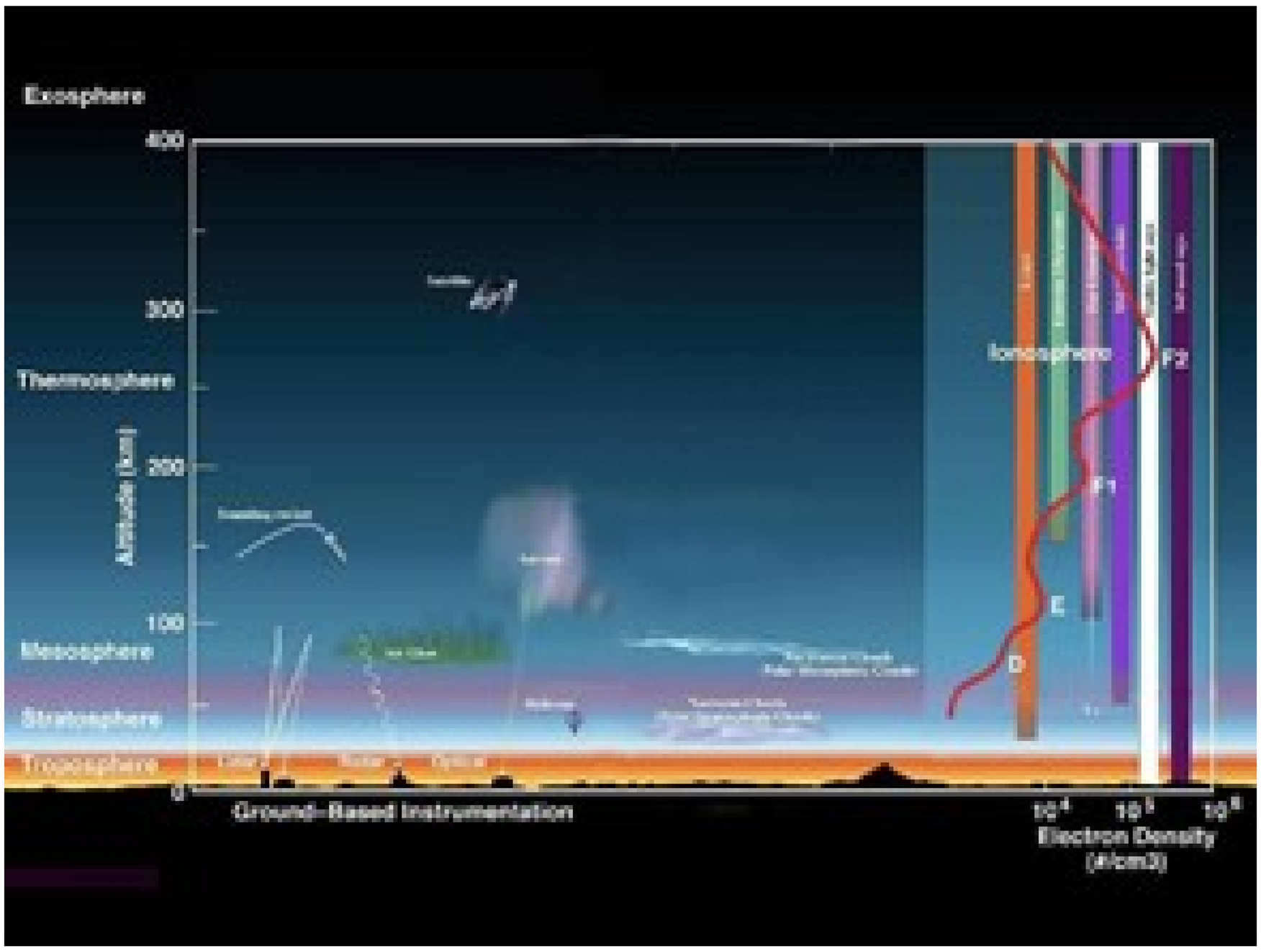


Figure 2: The layers of Earth's atmosphere. "Earth's atmospheric layers" by NASA, Public Domain.

The easiest way to imagine the atmosphere is as a blanket surrounding the Earth as it orbits through the freezing cold of space. Inside the blanket are many types of fibers: cotton, wool, polyester, etc. Under normal circumstances, the heat trapped by the blanket is enough to keep Earth warm without overheating. However, what happens as the fiber composition changes? As the blanket gains more and more heat-trapping fibers relative to others, the temperature inside the blanket goes up. This increased heat causes what is known as the "greenhouse effect." However, without at least some fibers that keep the blanket warm, Earth would not be able to sustain life as we know it. The planet underneath would be too cold. Therefore the issue is not the greenhouse gases themselves, but the increased concentration of them causing the greenhouse effect to worsen (Figure 3).

The atmosphere's stability keeps the Earth habitable, but if the atmosphere's composition changes too much it could result in drastic changes in temperature and affect all life on Earth. Before the industrial revolution, CO_2 concentrations generally fluctuated between 200 and 250 ppm (parts per million), with the levels directly before the Industrial Revolution averaging at 280 ppm as seen in Figure 4 (EPA, 2016). During the Industrial Revolution humans began burning large amounts of fossil fuels like oil and gas, and as the global population increased there was also an increase in livestock like cattle to feed the growing population. The post-industrial world has experienced a sharp increase in concentrations of greenhouse gases, including carbon monoxide, ammonia, and ozone. Figure 5 depicts that, in recent years, the atmospheric concentration of CO_2 has risen to 409.8 ± 0.1 ppm with no signs of slowing down. Atmospheric concentration of CO_2 is predicted to exceed 900 ppm by the end of this century (Lindsey, 2020).

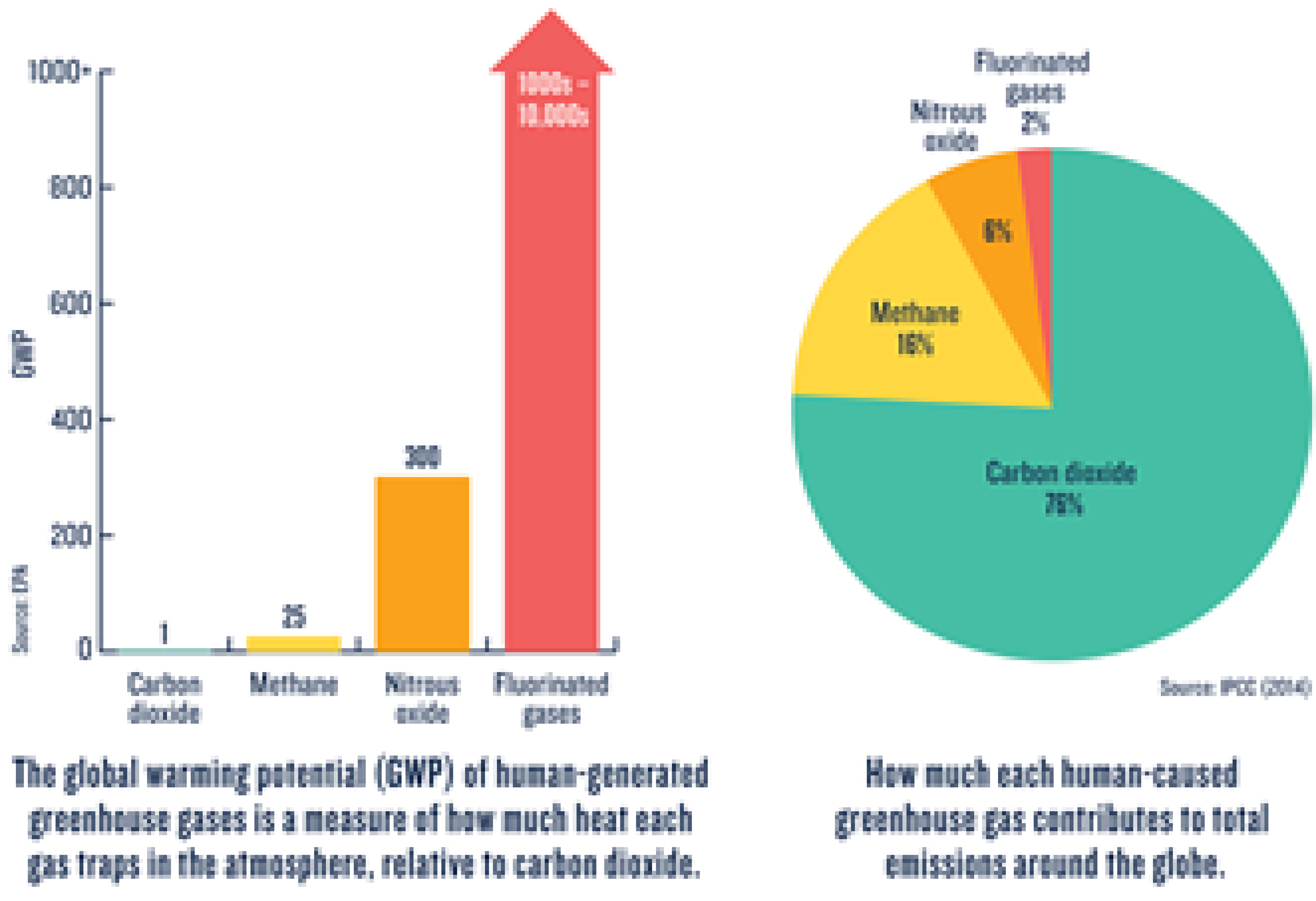


Figure 3: How humans are affecting climate change through greenhouse gases, "How greenhouse gases warm our planet" by NRDC, Public Domain.

A key factor in keeping the atmosphere stable is hydroxide, also known as OH. The OH ion binds with and removes pollutants and greenhouse gases from the atmosphere. As greenhouse gases increase, atmospheric hydroxide will be consumed at a more rapid pace than it is produced. This will result in decreased air quality, higher concentrations of other greenhouse gases, and higher concentrations of ozone in the lower atmosphere (where ozone is harmful, not helpful). Changes in the atmosphere are causing ripples which are being observed in many ecosystems. For example, the water vapor levels in the Arctic are rising and its atmosphere is becoming moist, increasing warming and exacerbating the melting of sea ice. Parts of northern India and eastern China are seeing an increase of atmospheric ammonia, which is decreasing their air quality. To see how the change in atmosphere is affecting the climate we need to look at the factors of how the Earth and climate behave, including the ocean, land surface, biosphere, and the cryosphere (Dessler & Parson, 2020).

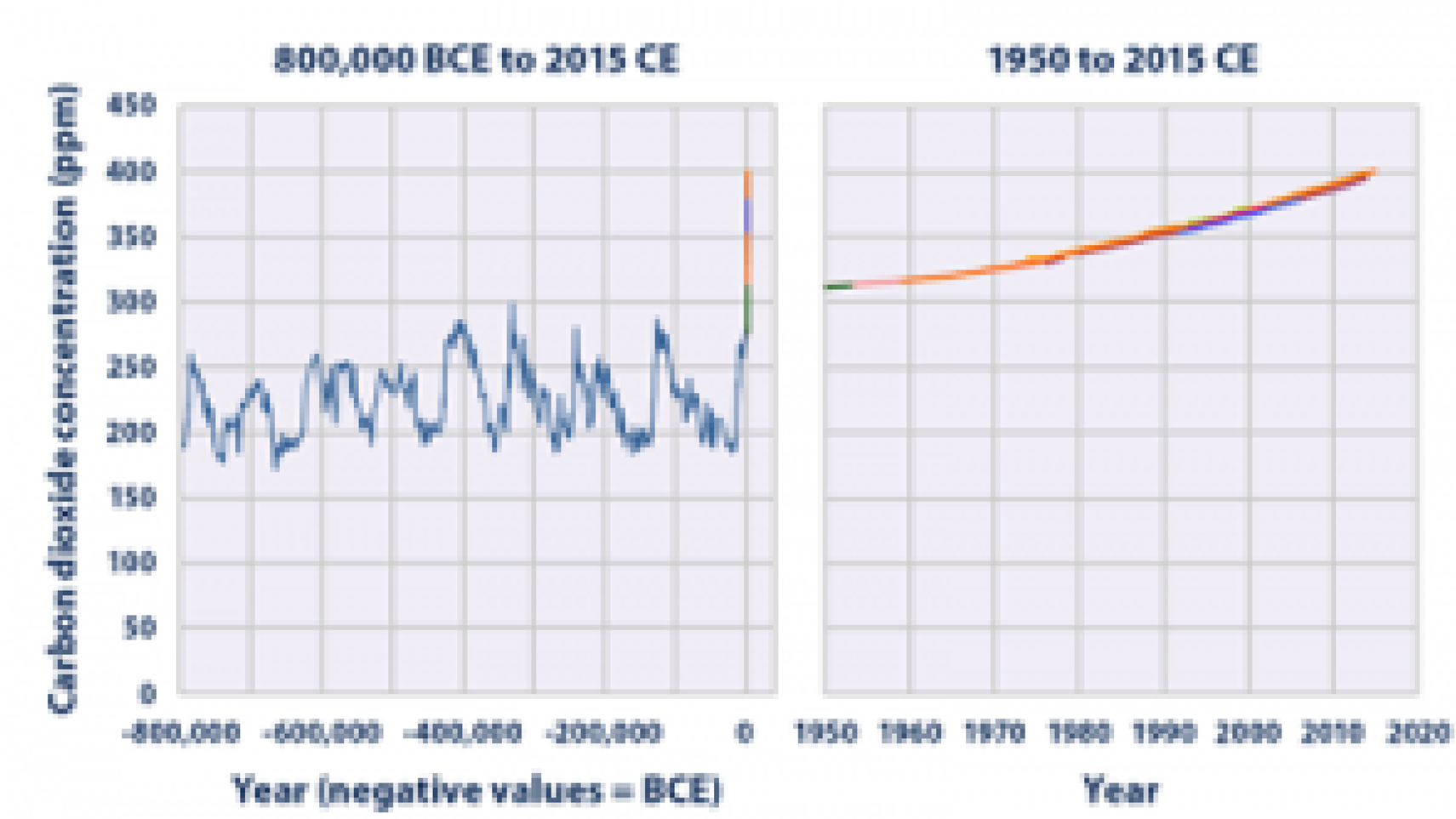


Figure 4: Atmospheric concentrations of CO2 in ppm. "Global Atmospheric Concentrations of Carbon Dioxide Over Time" by EPA (2016), Public Domain.

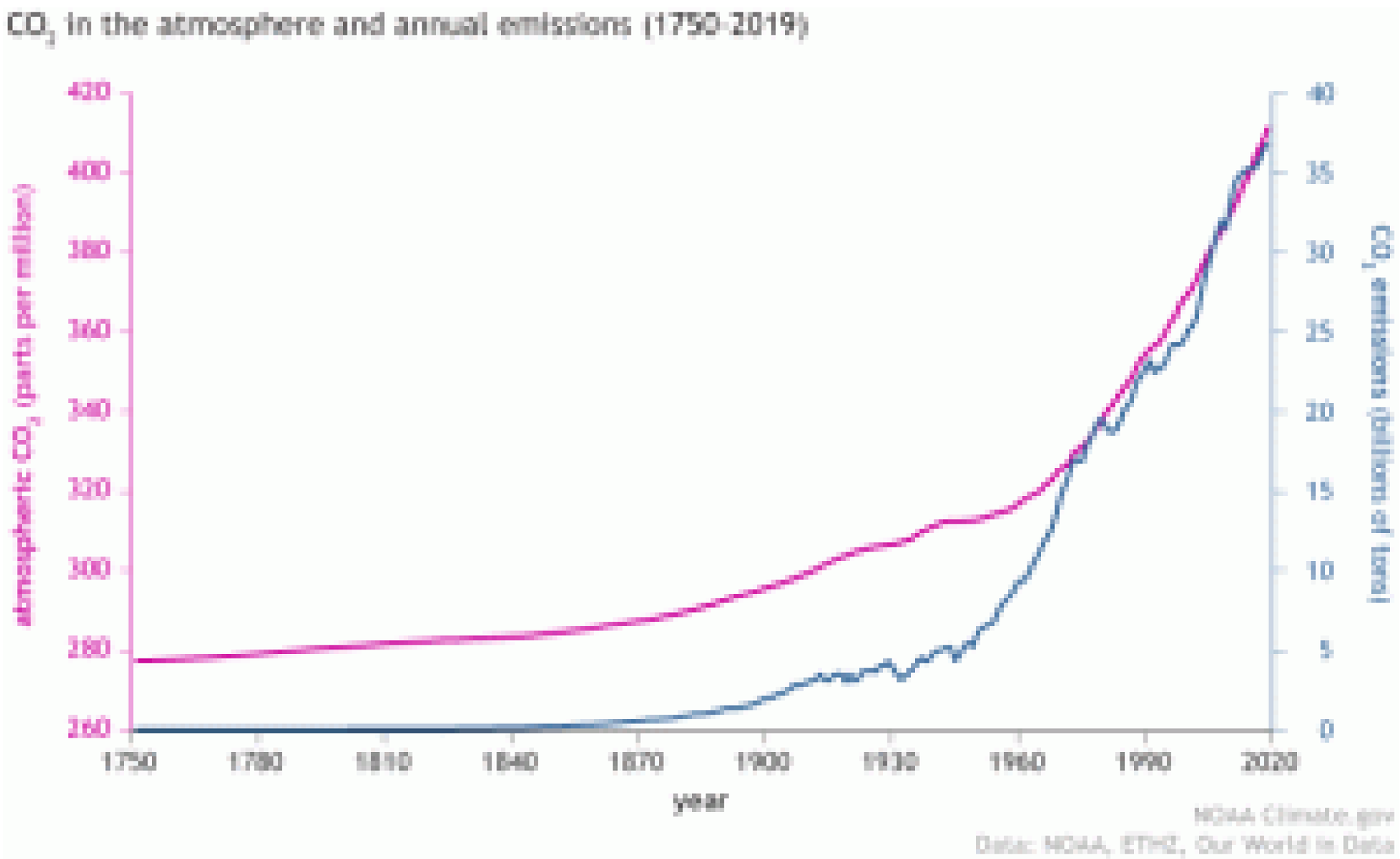


Figure 5: Carbon dioxide emissions and atmospheric concentrations since shortly before the start of the Industrial Revolution. "CO_2 in the atmosphere and annual emissions (1750-2019)" by NOAA, Public Domain.

Before the major growth of large human settlements, starting

around the last millennia BCE and getting larger from there, methane concentrations in the atmosphere fluctuated around an average of 500 ppb. Methane is the simplest hydrocarbon, made up of four hydrogens and one carbon. The increased concentration of methane from human activities is due to leaks of natural gas systems, livestock, decomposition of landfills, and is a major component in greenhouse gases. Methane is also emitted through natural sources such as wetlands, oceans, volcanoes, and wildfires. Methane has a lower **residence time**, or lifespan, in the atmosphere, but is more efficient in trapping radiation than carbon dioxide (EPA, 2020). As the human population grew, so did the concentration of methane in the atmosphere with the pre-industrial revolution concentrations holding steady at around 700 ppb. Methane concentrations have continued to rise with the atmospheric concentration of methane as of 2015 reaching approximately 1,800 ppb (EPA, 2020).

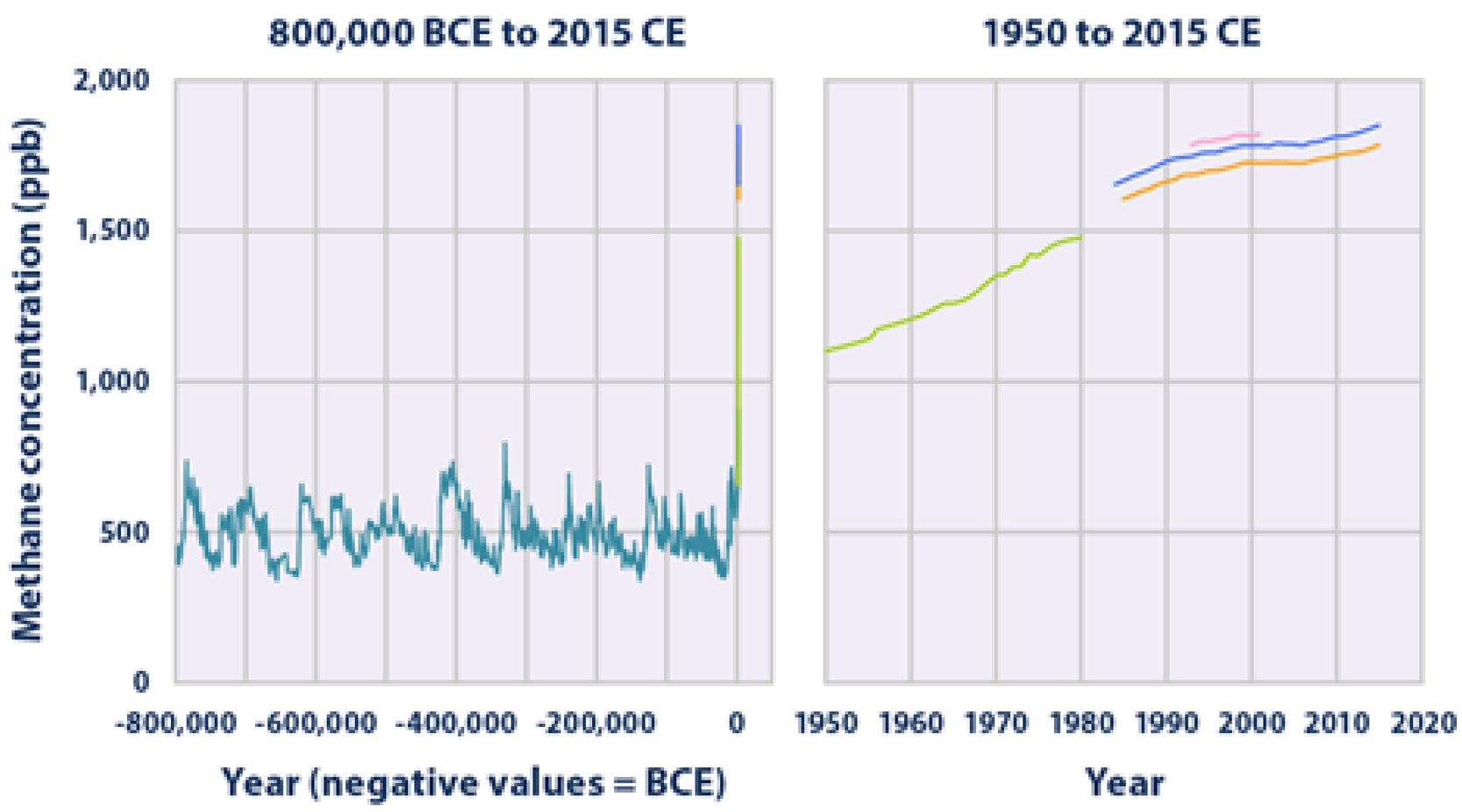


Figure 6: Atmospheric concentration of Methane gas in ppb. "Global atmospheric concentrations of methane over time" by EPA (2016), Public Domain.

Climate indicators are a set of parameters that describe climate change. The parameters are composed of key information to the

most relevant factors of climate change, which are temperature and energy, atmospheric composition, ocean and water, as well as the cryosphere (GCOS, 2018). One climate indicator, atmospheric circulation, has shifted significantly in recent years. As time has passed, the poleward center for atmospheric circulation patterns has shifted further north (Zhang et al., 2008). This means that the center of action where storms and warm winds originate in the tropics end up further into the Arctic Circle, bringing more warm air with them. This shift could be caused by increases in greenhouse gas concentrations, or it could be unrelated. In either case, this shift in atmospheric circulations has led to a concerning increase in the rate of sea ice loss inside the Arctic Circle (Zhang et al., 2008).

A large reason for the severity of atmospheric changes is that many natural processes on Earth affect the various concentrations of the atmosphere. The interactions between the surface of Earth and the atmosphere system, known as the physical surface-atmosphere exchange (Fowler et al., 2009), are incredibly complex and change with the climate. A prominent example of this is the human effect on the nitrogen cycle through intense production and usage of ammonia. The process that produces it, referred to as the Haber-Bosch process, produces ammonia for weaponry as well as fertilizers. Because of this method being accessible and relatively cheap, the number of people able to be sustained by 100 acres of farmland has grown from 1.9 to 4.3 from 1908 to 2008 (Erisman et al., 2008, 637). This means that more people were able to be born and fed, allowing for the people born during the population boom to survive and reproduce. Recent estimates place the percentage of the population supported by the creation of these soils at 48%, meaning almost half of the world's human population is only able to be alive because of these fertilizers (Erisman et al., 2008, 637). Higher population density, in general, correlates with higher carbon dioxide outputs (Kennedy, 2000). In addition, these fertilizers are not efficient. Only about 17% of the ammonia used in these processes enters our food, while the rest of it escapes into the atmosphere and surrounding ponds and waterways. From there,

the nitrogen changes the delicate balance of soils, increasing acidification and decreasing biodiversity. The waste also decreases ozone in the stratosphere and increases it in the troposphere (Erisman et al., 2008, 637-638). While additional ammonia and nitric oxide have been playing a role over the past century, it is far from the most influential gas.

Carbon dioxide is the most influential greenhouse gas connected to global warming, largely because of its connection to the increase of water vapor in the atmosphere. A study done in 1979 found that increases in CO_2 were directly related to higher levels of moisture in the atmosphere, higher rates of runoff, and more precipitation (Manabe & Wetherald, 1980, pg. 99).

Water vapor is the primary driver of the greenhouse effect, and since increased CO_2 puts more water vapor in the atmosphere, CO_2 is indirectly the reason for the Earth's growing temperature. Additionally, CO_2 is responsible for ocean acidification, which affects thousands of creatures who rely on a non-acidic ocean to create shells (Riebeek, 2011). In addition, this increase in ocean acidity combined with the warming of the ocean through climate change could result in lower levels of phytoplankton. These creatures consume carbon dioxide in the oceans, removing it from the atmosphere, and as their numbers shrink more carbon remains stuck in the cycle (Riebeek, 2011). This creates a positive feedback loop, in which the creatures die because it is too warm, leading to even warmer oceans.

Our atmosphere has such a strong impact on Earth's climate. The atmosphere depends on the systems that are connected (land, sea, ice). Our atmosphere encompasses everything on our planet. It holds the oxygen for our lungs and the carbon dioxide for plants' use in photosynthesis. It keeps us from being overheated or frozen. Every part of our lives and the lives of thousands of creatures are impacted by the atmosphere and its changes.

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changes in Arctic climate system. *Geophysical Research Letters*, 35(22), L22701. https://doi.org/10.1029/2008GL035607

2. Hydrosphere

By Isabella Cloves, Katherine Corbin, and Frank Ford

Abstract

The hydrosphere holds a major role on Earth and is vital to sustain all life present. Climate change has had a large influence on the hydrosphere, resulting in countless negative outcomes. The burning of fossil fuels has significantly changed the entire world including the hydrosphere by causing atmospheric CO_2 levels to rise. Skyrocketing CO_2 levels have not only influenced the warming of the planet, which has led to melting of Arctic ice, rising sea levels, a warming ocean and the bleaching of the coral reefs, but they have also produced an increase in the pH level of the ocean. These trends and many more predict a dire future for the health of the hydrosphere and the vitality of the Earth as a whole.

The Hydrosphere

The hydrosphere is the climate system on Earth which includes every body of water. Water is the most widespread substance on the planet, and is connected to all of the various climate systems on Earth. The water provided by the hydrosphere is one of the main

components of the life support system present on Earth and it is an essential component for the self-reproducing life. The hydrosphere also includes the water cycle that involves the movement of water through different phases (Fig 1). Earth has an abundance of water that makes it unique to other planets. Human interactions and climate change have greatly influenced the hydrosphere (Kundzewicz, 2008). The leading causes of this change include the burning of fossil fuels, nitrate pollution, and the absorption of CO_2 into the atmosphere. These changes to the hydrosphere have only amplified global warming more.

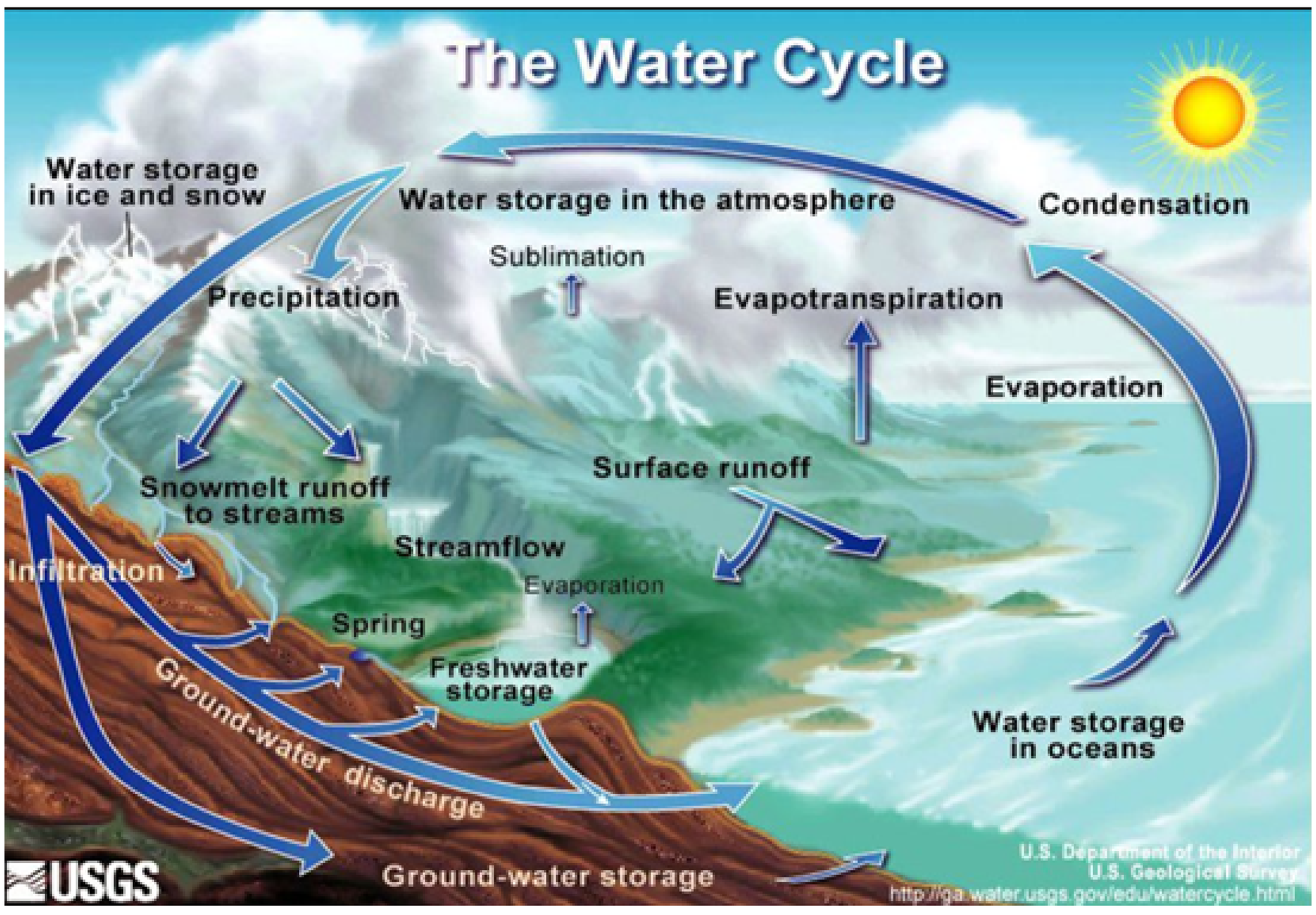

Figure 1. An illustration of how water moves through the land, atmosphere, and ocean. "The natural water cycle" by Howard Perlman, USGS. Public domain.

As a result of the changes caused by climate change, glaciers have melted and different bodies of water present on Earth have all been impacted significantly. In regards to human interactions with the environment, the atmosphere and the hydrosphere are both greatly experiencing the consequences from the burning of fossil

fuels. Once all of the fossil fuels present on Earth have been used, the effect from burning these fossil fuels and the emissions produced will cause irreversible damage to the hydrosphere from which the planet will not be able to recover (Valero et al., 2011). The hydrosphere plays such an important role on Earth as it supports and sustains life. Nitrogen pollution has also harmed the hydrosphere. The nitrogen pollution in the hydrosphere is caused by the mineralization of soil nitrogen, fertilizer, and animal or sewage wastes (Heaton, 1986).

As the burning of fossil fuels spews an excess of carbon dioxide into the atmosphere, some of the excess is absorbed into the ocean. Carbonic acid is formed when the CO_2 reacts with water, lowering the pH level of the seawater and making the ocean more acidic. As of 2013, the level was 0.1 pH lower than the pH level during pre-industrial times (Barford, 2013). The acidity of the ocean greatly affects the organisms living within it and many suffer as the water grows more acidic. One of those organisms affected is the very vital phytoplankton; microscopic organisms that photosynthesize to create energy. Phytoplankton make up the bottom of the food chain in the complex food webs that are present in the ocean. These phytoplankton also release dimethyl sulfide (DMS), which makes its way into the atmosphere and produces sulfuric acid (Barford, 2013). Sulfuric acid is considered a light aerosol and helps to form clouds in the atmosphere that reflect solar radiation rather than hold it in as greenhouse gases do (Osorio et al., 2008, Fig 2). If the production of DMS could increase as the CO_2 levels in the atmosphere increased, then it would create a negative-feedback loop, regulating the effects of climate change. However, that is not the case. The acidity of the ocean harms the phytoplankton and less DMS is produced. The reality is a positive-feedback loop in which the excess amount of CO_2 causes the Earth to warm, makes the ocean more acidic, lowers the amount of atmospheric sulfur, and impedes the natural cooling effect from light aerosols, therefore increasing global warming even more. DMS production does increase in warmer waters yet the damaging effects of an acidic

ocean overpower any increase in production due to higher temperatures (Barford, 2013).

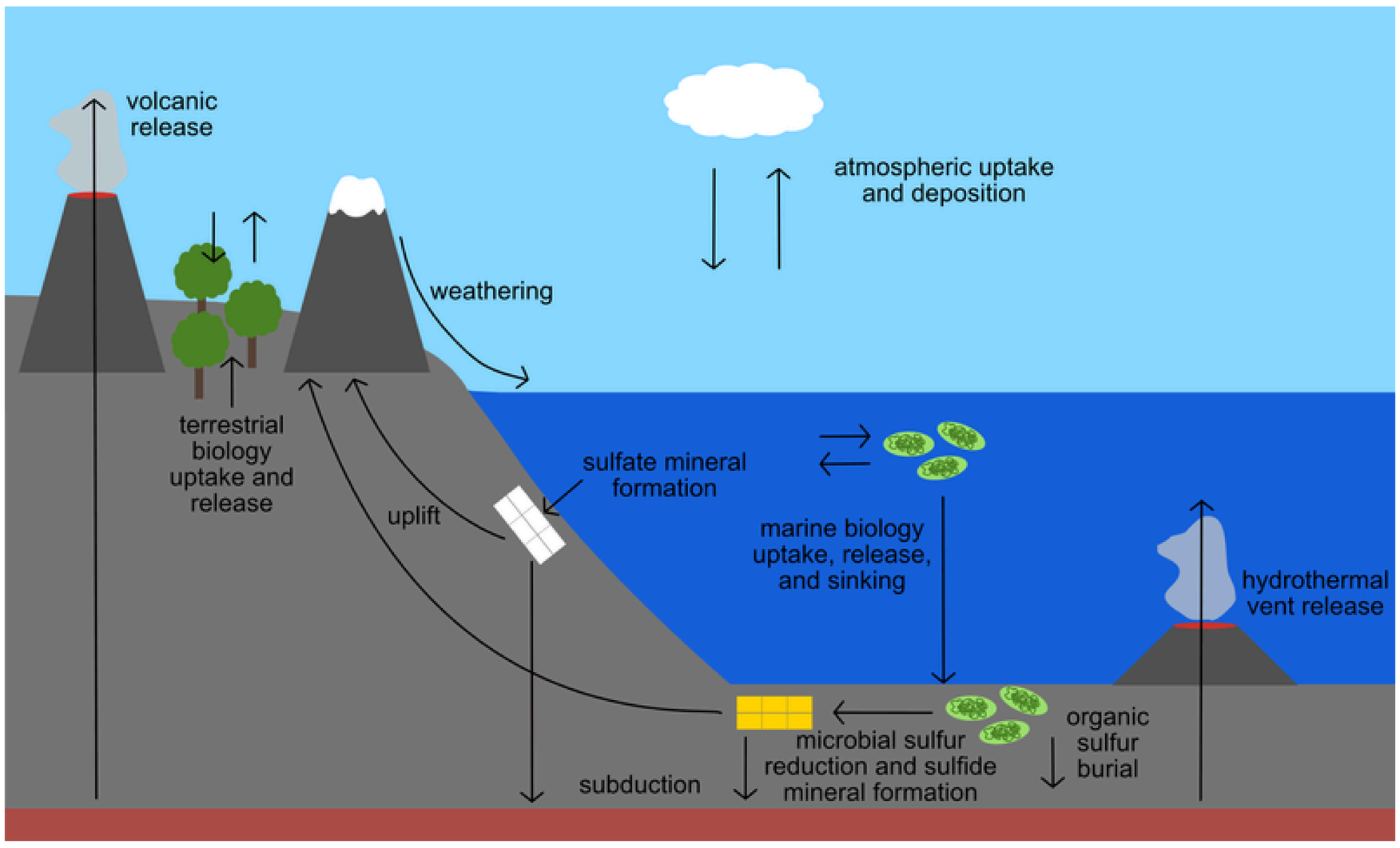

Figure 2. Diagram of the climatic role of sulfur. "An illustration of some common processes in the biogeochemical sulfur cycle" by GeoscienceHd, CC BY-SA 4.0

The impacts of climate change can be seen more clearly in specific parts of the hydrosphere. One special case, the Lake Baikal, located in southern Siberia, Russia, is experiencing strong climate change effects. Lake Baikal is the most biodiverse lake in the world due to the oxygen present in its depths and holds 20% of the world's liquid freshwater (Moore et al., 2009). Its location has extremely cold winters and is one of a few regions of Earth experiencing the most significant effects of climate change, with a 1.2 degrees Celsius increase in temperature over a century (Moore et al., 2009). This temperature change greatly affects the abiotic processes that are essential for maintaining the lake's current state and organisms. A warmer winter leads to less ice cover which reduces ideal conditions for the bloom of phytoplankton in the spring. This altered climate is also predicted to have an increase in snowfall which will cover the ice and block light from

entering the water, further harming the phytoplankton bloom. Since phytoplankton provide much of the energy for aquatic life through photosynthesis, this effect is devastating to all the diverse life in Lake Baikal. With less ice cover, the water is also exposed to the warmer air and therefore the surface temperature of the lake increases. Smaller photosynthetic organisms thrive in the warmer temperatures therefore bigger photosynthetic organisms are slowly phased out, leading to a lower energy production (Moore et al., 2009). Fish that thrive in colder water have to retreat deeper in the lake which disrupts the food chain by separating predators from prey. Wind patterns in the area change as well, causing the stratification of the lake water to change, leaving sections of the lake lacking in oxygen (Moore et al., 2009). These examples and many more show that climate change in Lake Baikal attacks from all angles and will have tremendous effects on the life that has occupied this lake for centuries.

Changes in the hydrosphere greatly affect the organisms that inhabit it. Fish and other marine life have been greatly impacted by climate change and its negative influences on the hydrosphere (Roessig et al., 2004). A key indicator of damage being done is seen in the melting of glaciers. The abundance of freshwater flowing into the ocean from melting glaciers can affect the ocean's circulation, changing how seawater moves across the world and affecting ecosystems and many human activities such as agriculture (Dyurgerov & Meier, 2005). The glacier runoff also causes a rise in sea-level which could devastate coastal communities. In a single year, between 2018 and 2019, there was a global rise in sea level of 0.24 inches (Lindsey, 2020). This incredibly rapid rate continues to increase each year. So why do scientists care so much about the rising waters? One reason is that many people reside on the coast, including forty percent of the US population (Lindsey, 2020). Millions of people's lives could be uprooted if the sea level reaches a high enough point. Even if floods don't lead to the demise of some cities, the saltwater can still contaminate drinking water and there will be less natural protection from storms. Rising ocean water is a

well-known result of melting ice, yet it creates many of these extra problems that often go unmentioned.

Figure 3. Melting Athabasca Glacier, Jasper National Park, Alberta, Canada. "Melting Toe of Athabasca Glacier" by Wing-Chi Poon, CC BY-SA 2.5

In addition to the changes brought on by melting glaciers, changes can be observed below the sea in one of the most important aspects of the ocean; the coral reefs. The coral reefs provide shore protection for coastal communities and jobs for locals in the area through fishing, recreation, and tourism. Additionally, they provide shelter for fish during the day and a hunting ground for them at night. The warming of the Earth's oceans has already caused catastrophic coral bleaching events and as the oceans continue to warm these events will occur more frequently (Mumby et al., 2011). Bleaching of the coral reefs results in a loss of vital habitat for many different species of fish and financial loss for coastal towns. After a thorough analysis of future ocean temperatures it has been determined that a 'quick' increase of one to two degrees Celsius in the ocean would not allow for coral reefs to acclimate or adapt. This would therefore result in the death or bleaching of many reefs

worldwide. All coral reefs have a limit to what fluctuations in ocean temperature they can survive. The predicted increase in oceanic temperature would pass the threshold of survival for a majority of coral reefs (Mumby et al., 2011). Once this threshold is exceeded, coral reefs will begin to die and this loss will be irreversible. While coral reefs can and will try to adapt to changes in ocean temperature, the quickness of future warming trends will not allow for thorough adaption, resulting in an enormous loss of the coral reef ecosystem.

Overall, the hydrosphere has been greatly affected by climate change. The burning of fossil fuels and nitrogen pollution have both had an impact on the hydrosphere. This has caused bodies of water to become more acidic due to higher amounts of CO_2 and negatively affect the species that inhabit it. Coral reefs have also been negatively impacted, harming the species that inhabit them as well. This change has also caused glaciers to melt and affect the hydrosphere's processes. The results of climate change have strongly impacted the hydrosphere and the organisms that rely on it and could soon wreak havoc on human activities.

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3. Cryosphere and Lithosphere

By Keelan Boyle, Jack Hanlon, Alexander Wadsworth, and Gabriel Ward

How the Cryosphere and Lithosphere Effect and are Affecting Climate Change

Abstract

The cryosphere and lithosphere are two of the five systems that make up the biosphere and are comprised of the frozen components of Earth and its crust, respectively. Both components have gone and are currently going through large scale transformations due to climate change, with a plethora of evidence and predictive models showing irreversible damage being inflicted. This transformation can be further understood through the analysis of leading driving factors, and counter measures can be developed in order to prevent further damage from occurring. How can something as simple as ice melting or changing magma flow affect something as significant as global climate? What kind of repercussions and benefits do these changes have on different environmental and social systems?

If your eyes have ever wandered toward the ground, what you happen to be looking at is the lithosphere. The lithosphere is all the mechanically rigid components that make up a planet, also known as the crust and upper mantle. The crust can be divided up into 7 sections called tectonic plates which roughly mirror the outline of the continents. These plates are in constant motion, occasionally grinding against each other, causing earthquakes and volcanic eruptions.

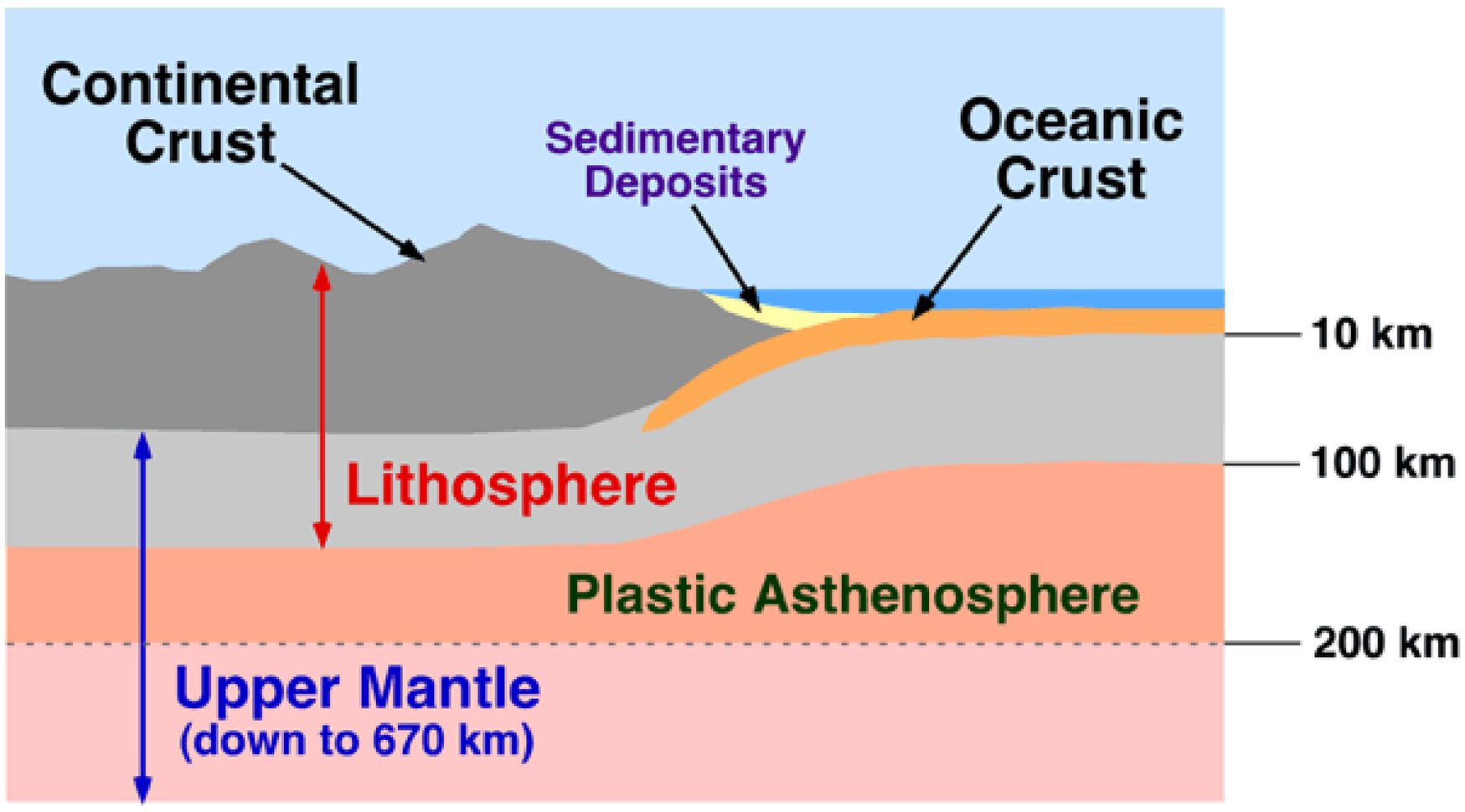

Figure 1: This figure shows the lithosphere, and breaks down the different components of the system. Pidwirny, M. (2006). Structure of the Earth. Fundamentals of Physical Geography, 2nd Edition.

In addition to tectonic plates, the lithosphere can be broken down into two major sections called the continental and oceanic lithosphere. The oceanic portion is much younger than the continental, as magma rises from ridges connected to the mantle and cools rapidly, forming new layers of crust. This new crust is eventually recycled in ocean trenches, where it sits and slowly gets buried by newer crust, creating underwater rock formations. An example of this cycle is shown in Figure 1, where oceanic crust is being recycled through the trench and new continental crust is being formed through volcanoes. There is also a difference between

the two in composition, with the oceanic lithosphere being made up of mostly **basalt**s, while the continental lithosphere is made up primarily of **igneous** and **felsic** rock. However, this warm, rocky region has an unusual counterpart that plays a large role in it's formation and changing.

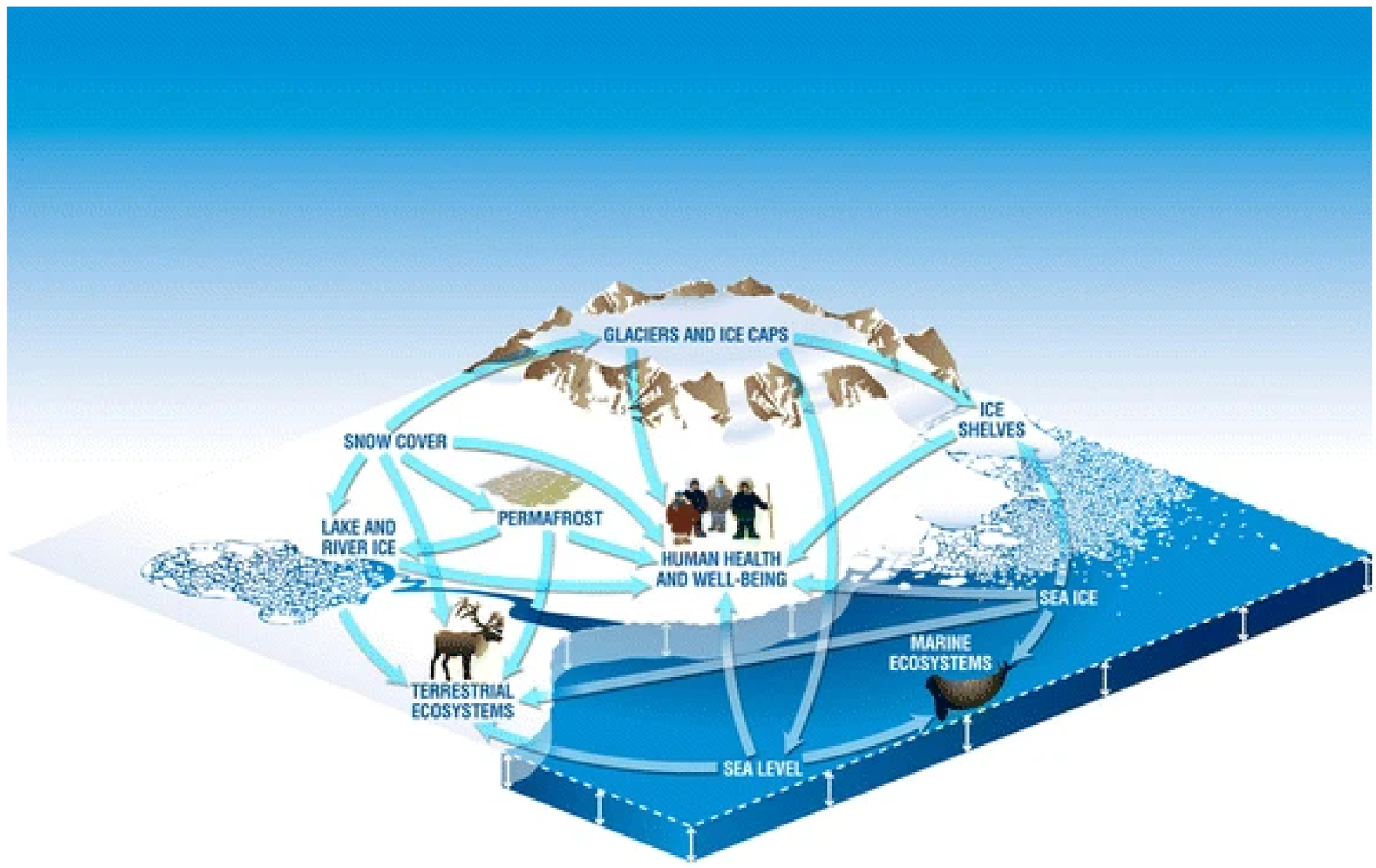

Figure 2: This picture shows the cryosphere and the effects it has on humans, terrestrial ecosystems, marine ecosystems around the world, as well as how each piece of the cryosphere effects the other. "Variability and change in the Canadian cryosphere" by Derksen et al., (2012), Open access.

Everyone has seen pictures of a barren tundra, snowy mountain tops, and icebergs. These are parts of what make up the cryosphere, which is comprised of everything on Earth that stays frozen for at least one month throughout the year. The most well-known components of the cryosphere are the Arctic and Antarctic, while other important forms include glaciers, **permafrost**, icecaps, and snow. Everything that comprises this system contains water and can melt and freeze again, resulting in an ever changing ecosystem. These systems, as shown in Figure 2, impact a wide variety of ecosystems and the wellbeing of humans showing how their existence is vital to life on Earth as we know it.

Figure 3: Changes in glaciers on Caucasus Mountains, Georgia. "Gergeti Glacier 1890-2011" by Levan Tielidze (distributed via imaggeo.egu.eu), CC BY 3.0

In latter decades, evidence of a changing cryosphere has been abundant. A decreasing presence can be seen from most aspects of the cryosphere. Significant negative trends in permafrost height have also been measured, most notably in the North Cascade glaciers' active layer, defined as the upper boundary that thaws periodically. Sites in Russia have additionally recorded an increase in the active layer by 1.7-5.5cm per year (Fountain et al., 2012), suggesting that a larger amount of the permafrost layer is melting every year. An area in New Hampshire has reported a reduction in maximum snow height by 25cm and 21 day drop in average yearly snow coverage over 53 years (Fountain et al., 2012). Sea and lake ice have also taken an impact in the recent decades with an average 3% loss of sea ice per decade and lake ice thinning at a rate of 2cm per year (Fountain et al., 2012). These statistics show a clear decrease in the ice cover and are an indication of a reducing cryosphere.

The net mass of a glacier is determined by the difference between the amount of ice that accumulates back onto it and the amount of ice that melts off the glacier, if this net mass is negative then the glacier is deemed to be receding. Measurements of current North Cascade glaciers show that their volume has decreased by 30% since 1984 (Mauri, 2020). This observation is further reinforced by Figure 4, which displays the average mass balance of glaciers around the world. Most of these glaciers are connected to the ocean, meaning that if they melt there would be a significant rise in sea level, nearing 58 meters at its maximum. In recent decades, the ice flow in the Pine Island Glacier terminus has increased from 1.5 km/yr to 5 km/yr, contributing to a 4.5mm sea level rise (Shepherd et al., 2018). The rising sea level is a direct representation of a changing cryosphere because the mass lost from ice turns into the height gained by the oceans.

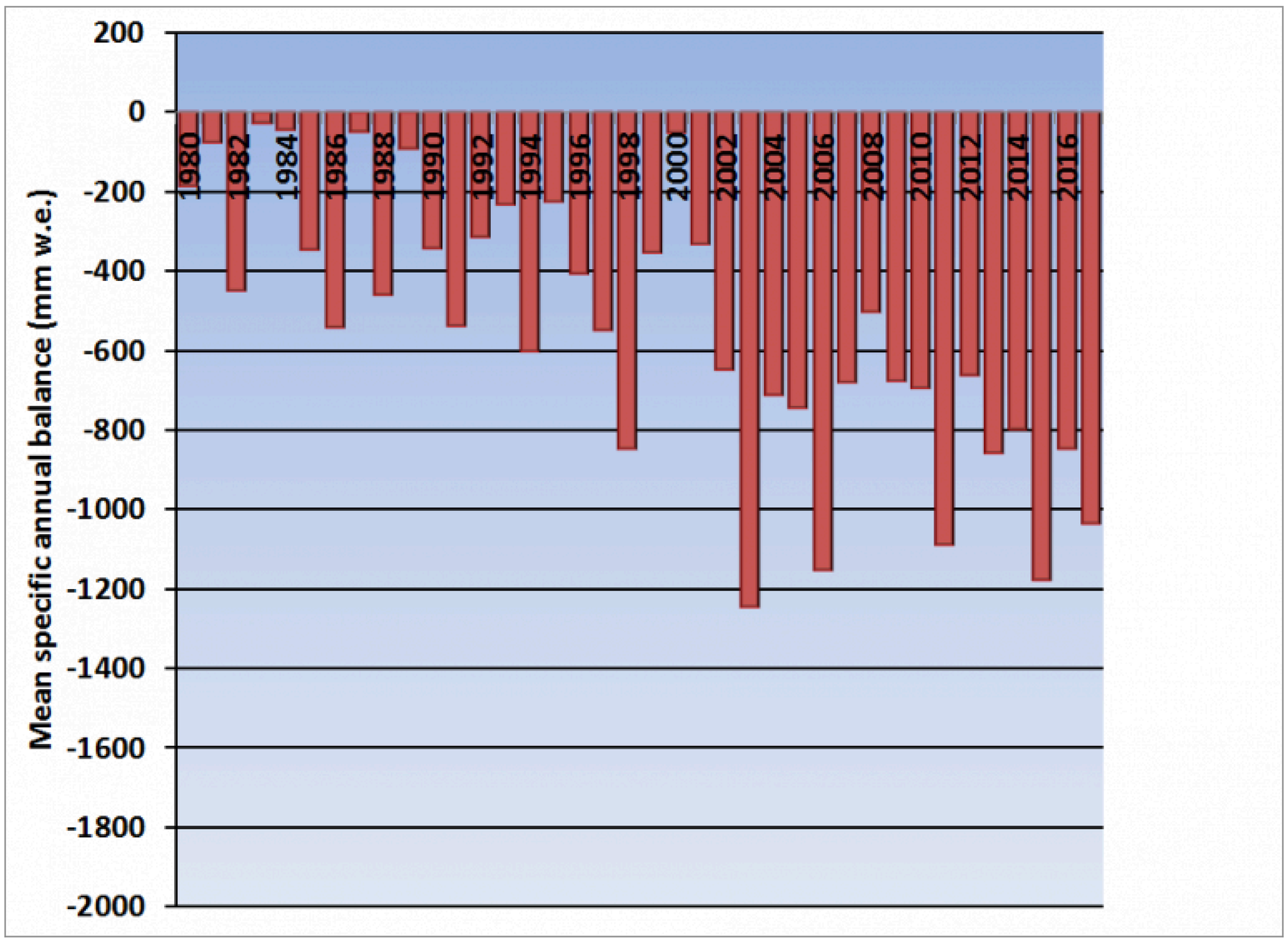

Figure 4: Above is the global mass balance of glaciers since 1980. It is dominated by volume loss and an increasing negative balance. "Chart of annual and cumulative glacier mass balance from World Glacier Monitoring Service Data" by Mauri Pelto, CC BY-SA 3.0.

Proof of a changing lithosphere is more difficult to conceptualize because a rising global temperature would have a minute impact on the Earth's crust and mantle. However, the climate system can still be influenced indirectly, mainly by the movement and actions of glaciers. As glaciers melt, weight is relieved from the pieces of mantle they lay upon, creating areas of changed elevation allowing new magma flow deep underground. As these regions return to their shape from before glacial depression, magma is brought further to the surface, warming the new volcanic region. It has been found, through a study done in Iceland, that this decrease in pressure can result in changing magma melt rates within the mantle, which can lead to a greater probability of volcanic eruptions (Swindles et al., 2018). In conjunction with the previous statement, the lower pressure can also result in an uplift in tectonic plates and

sea level which have been recorded to be as high as 120 meters in the past (Mozie et al., 2014). A rise in the oceanic tectonic plates and the resulting increase in sea level are obvious indications of transforming lithosphere.

To see why changes are occurring within the cryosphere and lithosphere, the driving forces and causes must be identified. It is easy to claim that as global temperatures rise, glaciers, permafrost, and icecaps will melt, so it's better to. One way the cryosphere keeps the climate regulated is through surface albedo, which is defined as the ratio of radiosity to the irradiance (flux per unit area) received by a surface, or the ratio of sunlight reflected to the sunlight absorbed by Earth. This process is of paramount importance to the globe, as snow and ice reflect massive amounts of heat and energy back into space and span over wide regions of land. On top of global temperatures rising, Bedford (2009) revealed that multiple components of the cryosphere house greenhouse gasses deep beneath their surfaces. This causes the cycle to become an accelerating positive feedback loop, melting the cryosphere, while simultaneously changing the lithosphere.

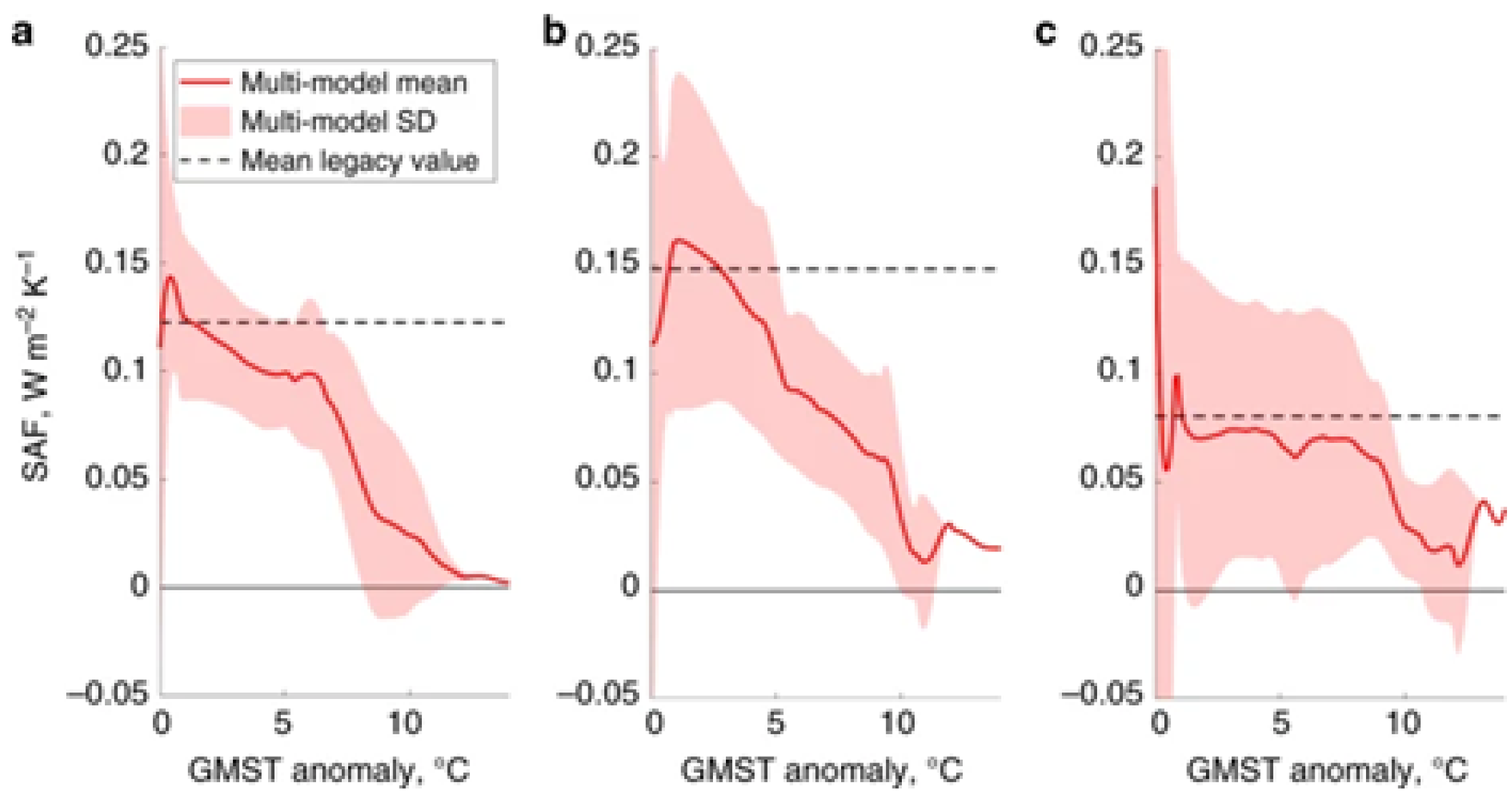

Figure 5: Pictures above is a graph showing the relationship between surface albedo feedback in the Artic, the Northern Hemisphere, and the globe. From this graph it can be said that as SAF drops, the global mean surface temperature raises. "Fig. 2" by Yumashev et al. (2019), CC BY 4.0

Within the lithosphere, change comes differently than it does with the cryosphere. Exposed regions of lava due to previously mentioned glacial melting, as seen in Figures 3 and 5 can lead to excessive heating of the lithosphere and atmosphere, and contribute to the number of aerosol particles immensely. Paired with the combination of soil disturbance for agricultural purposes as well as mass deforestation, the lithosphere is ever changing and contributing to climate change in horrifying ways (Ostberg et al., 2018). These parts of the biosphere are extremely important to humanity's current way of life and its certain that with our current path, we'll lose these systems and cause massive amounts of irreversible damage.

With the Earth changing, what environmental and social systems are affected? Specifically, the melting of the cryosphere can affect ice covered regions, river systems, and coastal lowlands. Melting ice significantly impacts migration patterns, hunting grounds, and the living conditions of numerous species. In fact, the changes brought by the destruction of the cryosphere are occurring more rapidly than some species can adapt to. This applies to humans as well, with human settlements in danger of being flooded due to the possibility of rising sea levels. The damages caused by floods makes it increasingly hard for communities to function due to the cost of repair and protection. Cultural hubs like the Maldives (5 feet average elevation; CIA, 2020), and Venice (3.2 average feet elevation; Bock et al., 2012) are most vulnerable as they are coastal lowlands. Water levels could increase as much as eight feet in the next 100 years, as estimated in Figure 6, meaning specific countries can lose half of their land.

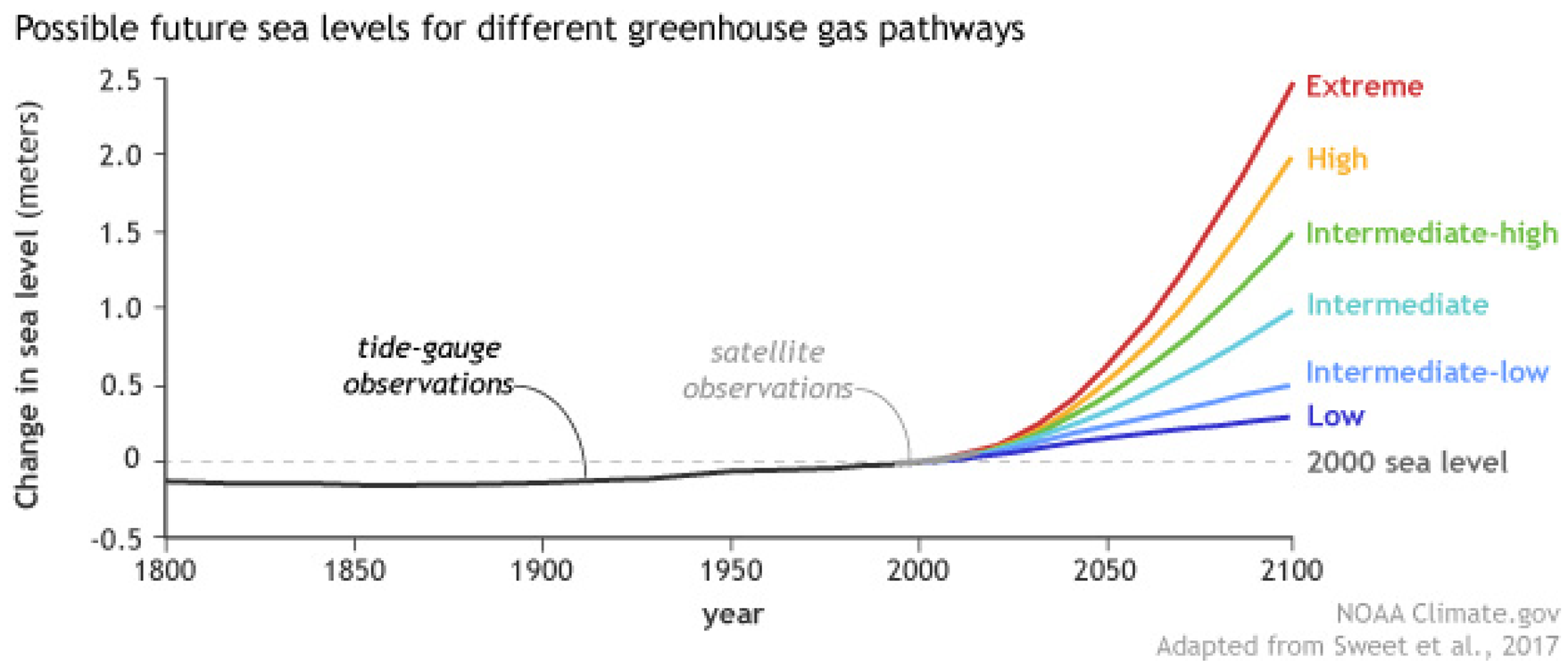

Figure 6: The graph shows the increase in sea level in the last 200 years and the range of sea level rise in the next 80 years. "Possible future sea levels for different greenhouse gas pathways", NOAA Climate.gov, Adapted from Sweet et al. (2017), Public Domain.

In addition to the sea level rising, the salinity of freshwater ecosystems also increases, wreaking havoc on all water systems in the area. This will affect freshwater supply and lead to numerous species suffering and dying, potentially including humans. Families and individuals who can afford to treat/pipe in fresh water or move away will be fine, unlike those who would be forced to live with the changes (Page & Daniel, 2019).

With an increase of seismic and volcanic activity, the systems being affected are those around fault lines, and volcanoes, increasing positive and negative impacts. This includes more soot in the air which can reflect light, and richer farmland due to settled soot (UC Santa Barbara). The primary negative effect of this is an increase in volcanic eruptions, and a possible ice age. On top of this the soot can cause breathing problems like **silicosis** and can even damage people's eyes (Buis, 2019; CDC, 2018). With more movement of the tectonic plates, earthquakes also become more common. Even though an earthquake takes a few seconds communities could still feel the impact for years. As climate change continues, all these issues will become magnified and those who can do the least about

it will be hit the hardest. As climate change continues to develop how will humans cope and adapt with it?

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4. Biosphere

By Gabriel Espinosa and Daniel Shea

Abstract

The durability of bio-organisms has allowed for their persistence on Earth for over 3.5 billion years. As our planet has changed over time, so has life, creating a cyclic ebb and flow of resources throughout various living and non-living environments. The evolution and adaptation to climatic and ecological differences over time explains why all species on Earth inhabit specific regions that fit their developmental needs. The stability of Earth systems are now under threat as anthropogenic climate change increases the atmospheric concentration of greenhouse gases at a quicker rate than can naturally be extracted. Consequently, life within our planet's biosphere has been forced to adapt to rapid changes in their environments. What is responsible for our current climate emergency and what will survive its wake?

A Changing Climate on the Biosphere

The biosphere is the area of Earth known for supporting life in the atmosphere, hydrosphere, and the geosphere. The interactions between these systems subdivisions allow life to flourish on this

planet. The hydrologic cycle is critical to life as it describes the movement of water through the planet, starting in liquid bodies such as our oceans, then evaporating into the atmosphere from the presence of heat and light, and finally raining down upon the surface, repeating the cycle again. This motion of the ocean brings water to plants and animals while also recycling nutrients across various ecosystems. Biogeochemical cycles such as the carbon cycle continue to describe the movement of inorganic compounds between organisms and the atmosphere, hydrosphere, and geosphere. When discussing climate change, the carbon cycle immediately takes center stage as it demonstrates how carbon dioxide in our atmosphere makes its way into our oceans and forests as a closed loop (Schwartz, 2014). Problems arise when more carbon is added to the system than can be naturally cycled out.

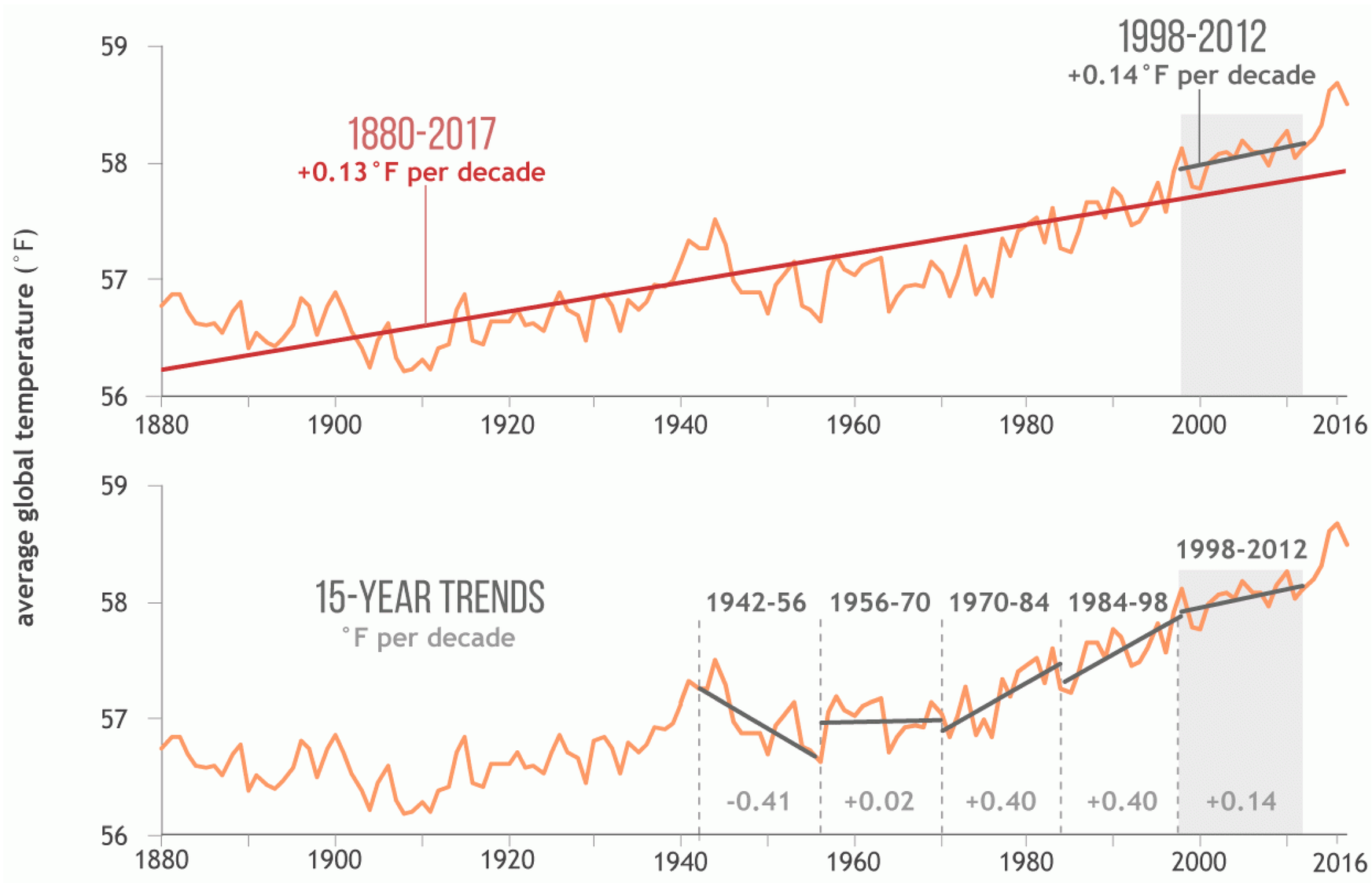

Figure 1: (Top): A graph of average global temperature starting in the year 1880 and ending in 2016. A line in red represents the average trend of the data over the time period recorded, showing a clear upwards trend in global temperature. (Bottom): A graph plotting the same average global temperature over time data is the chart above it, however, showing trends of only 15-year periods starting in 1940 and ending in 2016. These trends show some deviation from the top graph while still pertaining to the general increasing trend. "Long-term (1880-2017) global warming compared to short-term temperature trends", U.S. Environmental Protection Agency, 2018, Public Domain.

As most know by now, the climate is changing. Most notably, the average global temperature of Earth is increasing at a rapid pace (Figure 1). While likely definitive proof for most, there are other key indicators of our changing climate that deviate from the standard temperature model.

The oceans of Earth cover roughly 70% of the planet and act as a critical component of the carbon cycle, absorbing CO_2 from the atmosphere. However, the more carbon the oceans take in, the more acidic it becomes. When carbon dioxide dissolves in ocean waters it reacts with water (H_2O) to form carbonic acid (H_2CO_3), lowering the pH and increasing the acidity of the water. In just 24 years, the oceans have gone from an average pH of 8.12 to 8.07 (Caldeira et al., 2007). This is a small, yet consequential change, making ocean acidity a key indicator of climate change.

Nearly 68% of freshwater on Earth is held in ice, whether it takes the form of Arctic and Antarctic ice sheets or mountain glaciers, a resource vital to the survival of humankind and other species alike is melting away. In the last 16 years alone, 5,000 gigatons of polar ice has melted, enough water to fill 400,000 Olympic swimming pools. This rapid rate of ice melt has contributed to an average sea level rise of three-fifths of an inch per decade since the 1880s. Given the accelerating rate of global temperature rises in the past few years, this rate has increased to nearly one inch of sea level rise per decade (EPA, 2020a).

The ecosystems of our planet are the cradles that nurture life, representing diverse geography, plant, and animal species. Over millennia these species have adapted to depend on each other for the necessities of life, creating a stable biotic system. Our changing climate has slowly been disrupting these fine balances, forcing a quick shift in the life an environment can sustain (Figure 2). Various climate models created by scientists at the California Institute of Technology exhibit a global shift in up to 40% of ecosystems such as forests and grasslands to more desert like conditions (Buis, 2011). These consequences are already underway in 168 countries as the

phenomena of desertification strips fertile land of its nutrients turning once lush grasslands into arid wasteland (King, 2013).

Figure 2. Afghanistan / The drought in Jawzjan province of northern Afghanistan has made the land unfarmable. V. Tan, 2016, CC BY-NC-SA 2.0

At first glance it may appear that the changes in average temperature are inconsequential when compared to the massive scale of the planet. However, the ecosystems of Earth have adapted within a range of variance centered around global averages. Within their habitats, plants and animals can survive the natural fluctuations in weather and resource conditions. Climate change has shifted averages of nearly every environmental normality, moving the system out of equilibrium. (Wong, 2015) One may argue that the planet has experienced extreme climate changes in the past and how species adapt over time. While accurate, such changes took place over a duration of millions of years whereas anthropogenic climate change has irreversibly altered the planet in just a few hundred years, not biding enough time for natural systems to adjust.

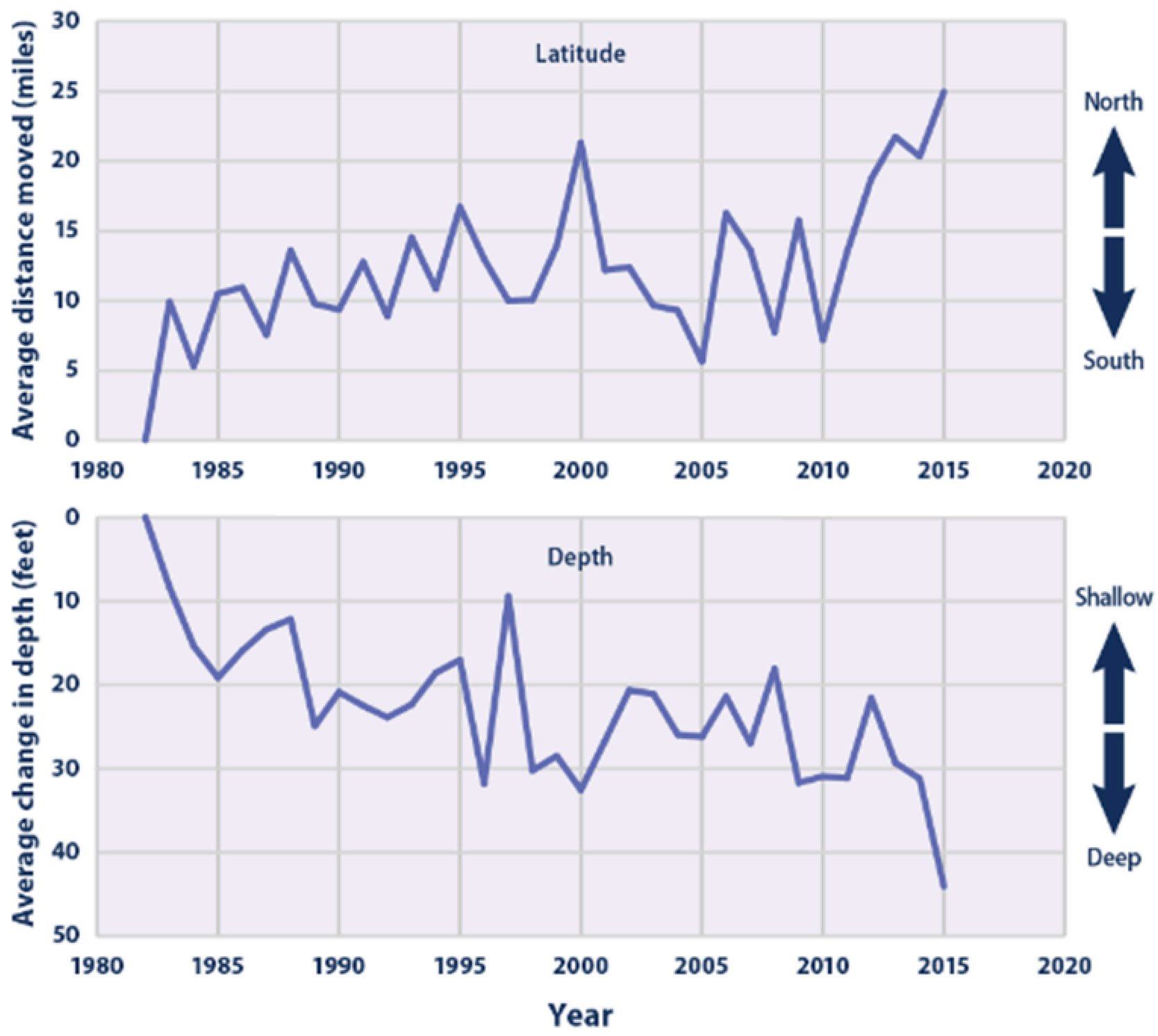

Figure 3: (Top): A graph displaying the directional biomass distribution of 105 marine species over time, the graph indicates a trend in a northward latitude movement. (Bottom): A graph displaying the biomass depth distribution of 105 marine species over time, the graph shows a trend in marine life movement to lower depths. "Change in latitude and depth of marine species, 1982-2015" by U.S. Environmental Protection Agency, 2016, Public Domain.

As ecosystems move and disappear their inhabitants are forced to adjust with them, creating an interesting metric to observe when evaluating climate change regarding biological distribution. On average, marine life has been moving to deeper and northward waters, two regions that can be associated with cooler average temperatures (Figure 3). Similar trends can be observed in bird **migration**, which has also shifted further north. This means birds are not traveling as far south during winter migration in order to stay in their preferred temperature range (Travis, 2003). Given the rigidity of biological systems such as migratory patterns,

investigating their changes can provide a useful insight into our changing world. The warming climate has also allowed for some invasive species of plants and animals to expand outside their typical range into different ecosystems, disrupting natural habitat balance. An example of this would be boreal forests which span the northernmost regions of the planet, where trees have begun expanding coverage into the arctic tundra, disrupting indigenous animal habitat (EPA, 2020b).

Climate change can be seen across the globe through both living and non-living systems. However, it is unknown exactly who or what is driving these rapid changes to our planet's fragile environments. In short, all evidence points to the unfortunate truth that climate change is **anthropogenic**, meaning caused by humans. Since the late 1700s, civilizations around the globe have been burning fossil fuels at an unprecedented rate as societies industrialize. Industrial practices and energy production account for roughly 46% of total greenhouse gas emissions (Dean et al., 2018), the result of burning carbon-based fuels. As industry expanded so did the global population, from only 1 billion in 1800 to now over 7 billion, leading to the industrialization of agriculture to feed the growing populous. The expansion of factory farms in the mid-1900s saw the increase in global livestock populations by nearly 300%, subsequently accelerating the production of the greenhouse gas methane, a byproduct of livestock cultivation. Figure 4 shows the increase of methane (CH_4) in the Earth's atmosphere is due to livestock production, as it accounts for roughly 30% of today's atmospheric makeup of methane (Smith et al., 2009).

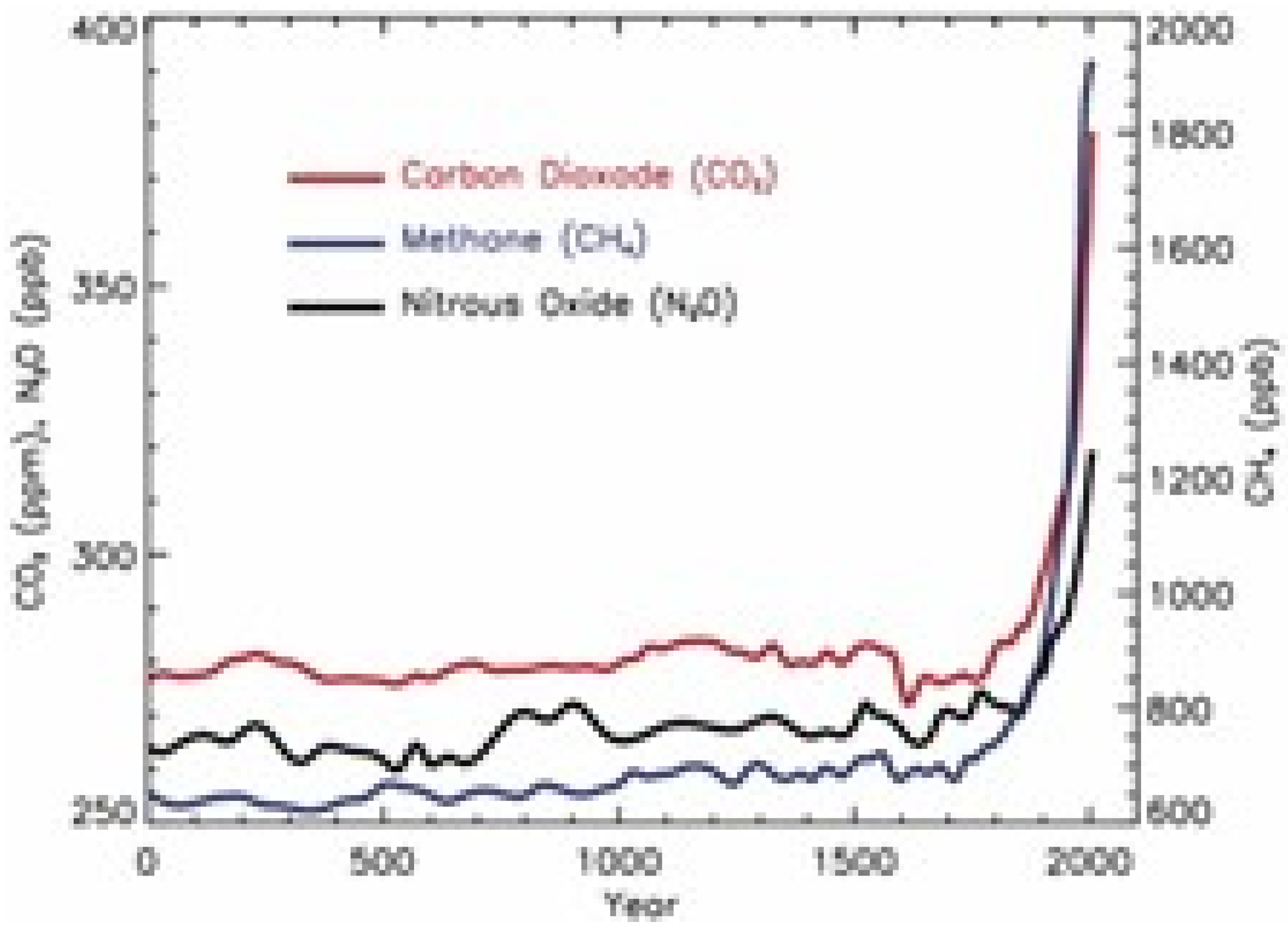

Figure 4: Graph of the atmospheric concentration of greenhouse gases over time given data collected from ice core samples. The graph displays clear upwards trends of carbon dioxide, methane, and nitrous oxide, all biproducts of modern industrialization and commercial practices. "Concentrations of greenhouse gases from 0 to 2005", FAQ 2.1, Figure 1, in Chapter 2, IPCC Fourth Assessment Report by Forster et al. (2007)

Greenhouse gases in our atmosphere absorb infrared light radiated from our planet's surface and originating from the sun, thus trapping heat that would otherwise be able to escape into space. The heating of our planet has started affecting our day to day lives, with stronger and more severe weather patterns, hotter summers, and cooler winters. As seen in Figure 5, a positive feedback loop has formed due to increased greenhouse gas concentrations. The increase in greenhouse gas emissions results in severe wildfires and causes ice melt to release high quantities of stored carbon.

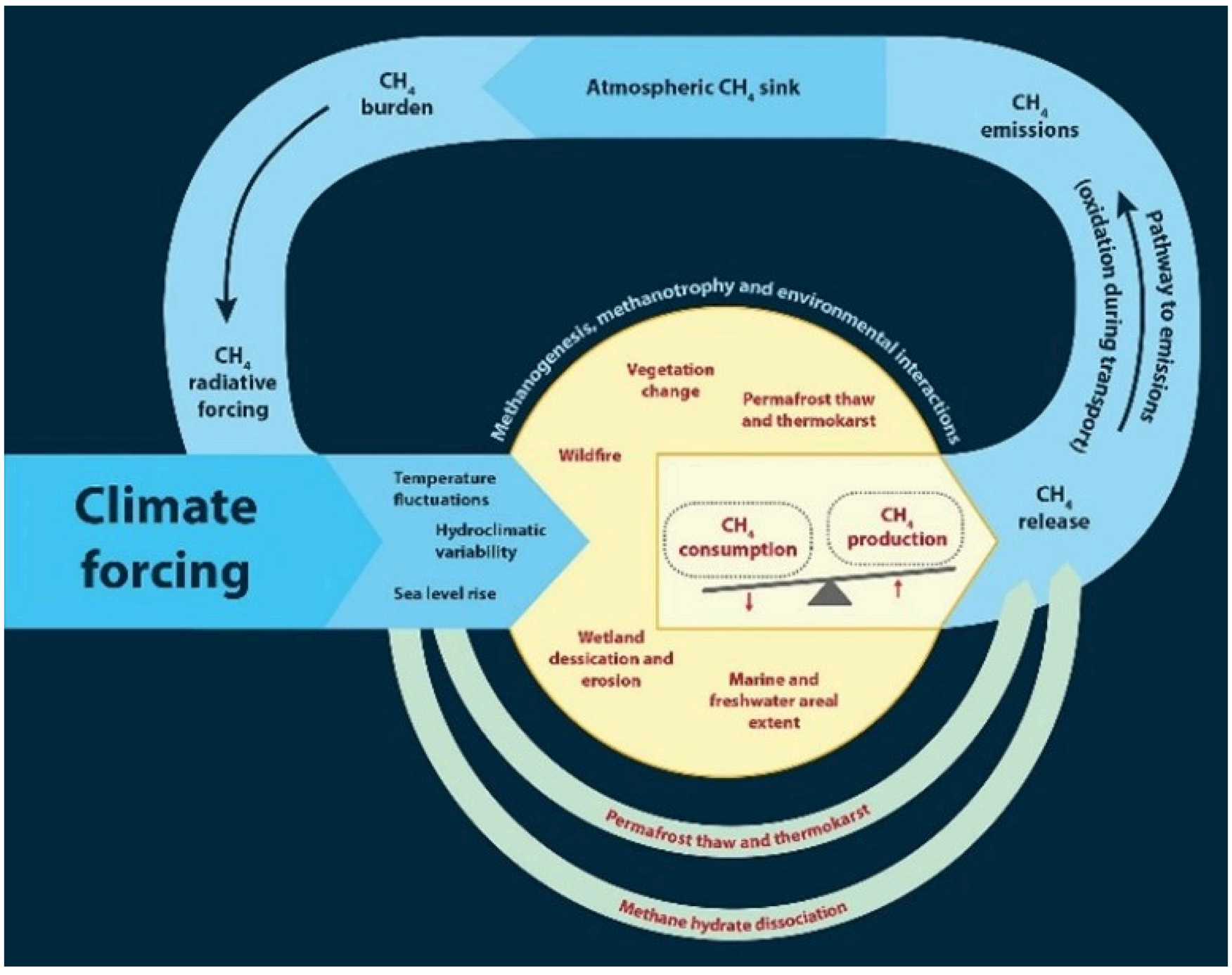

Figure 5: This graphic displays the positive feedback loop of methane in the atmosphere. Starting with methane production which then warms the planet, increasing wildfire frequency, permafrost thaw, habitat destruction, sea level rise, and more. This consequently releases more methane into the atmosphere, thus fueling the cycle once more. A similar feedback loop can be seen with carbon dioxide emissions with lots of overlap between the two. "Figure 7" by Dean et al., (2018), CC BY-NC-ND 4.0

The effects of climate change on ecosystems is extensive and ever growing. The greatest driving force of species extinction and endangerment is habitat loss. The Amazon rainforest is home to some of the greatest biodiversity on the planet. Unfortunately, due to the high agricultural productivity of the region, over 20% of forest land has been burned to make room for farmland since 1970. Scientists predict at least 38 species indigenous to the Amazon will go extinct by 2022 as a result (Sommer, 2020). However, habitat loss is not restricted to direct human land intervention such as urbanization and deforestation.

In the marine realm, ocean acidification has devastated coral reef

populations while decreased temperature variability due to ice melt has resulted in less ocean nutrient circulation and cold-water upwelling. This means many surface nutrients are sinking deeper into oceans and out of the range of shallow water microorganisms like plankton, which produce almost 85% of the oxygen in our atmosphere and act as the base of the oceanic food web (Moore, 2018). The survival of all living organisms on the planet is dependent on the trillions of microorganisms in the oceans. The consequences of our changing planet will put great survival pressures on these species and ecosystems, making their way through the food chain and eventually to the homes of billions of humans alike.

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PART II

SOCIAL IMPACTS OF CLIMATE CHANGE

In the next set of chapters, students investigate major societal impacts of climate change. First, students explain the major impact, including its main components. What impacts in the topic are being felt now and where are they being felt? What does the future look like in relation to your topic? Next, students connected their social topic to the climate systems involved in the impacts. Finally, students explored actions that regions are taking to both adapt to these impacts and to try to mitigate future impacts.

In Chapter 5, a team of students explores the reciprocal relationship of how climate affects food systems and how agricultural practices in turn affect climate systems. The reliance on water for drinking water, agricultural systems, and ecosystems and changes in water systems related to climate are presented in Chapter 6. Students examine climate impacts on human health via spread of infectious disease with increased precipitation and temperature in Chapter 7. In Chapter 8, students in explain that inequalities related to climate change are exacerbated for citizens, especially women, in **Majority World countries** suffer greater risks and loss than citizens in **Minority World countries.**

5. Climate Change Impacts on Food Systems

By Keelan Boyle, Isabella Clowes, and Katharine Miller

Our society's food system is comprised of growing, processing, transporting, and selling food. It is important because all humans rely on food to survive. However, climate change threatens to take down the current structure. With the changing climate, farmers are having trouble maintaining a consistent crop yield. Because of this struggle, farmers are using more fertilizers and are cutting down more trees to survive (Gibbens, 2019). This cycle disproportionately impacts the poor, especially those living in rural areas who rely on agriculture to survive. How can this loop of destruction be broken? What can be done to combat the impact of climate change on our food system?

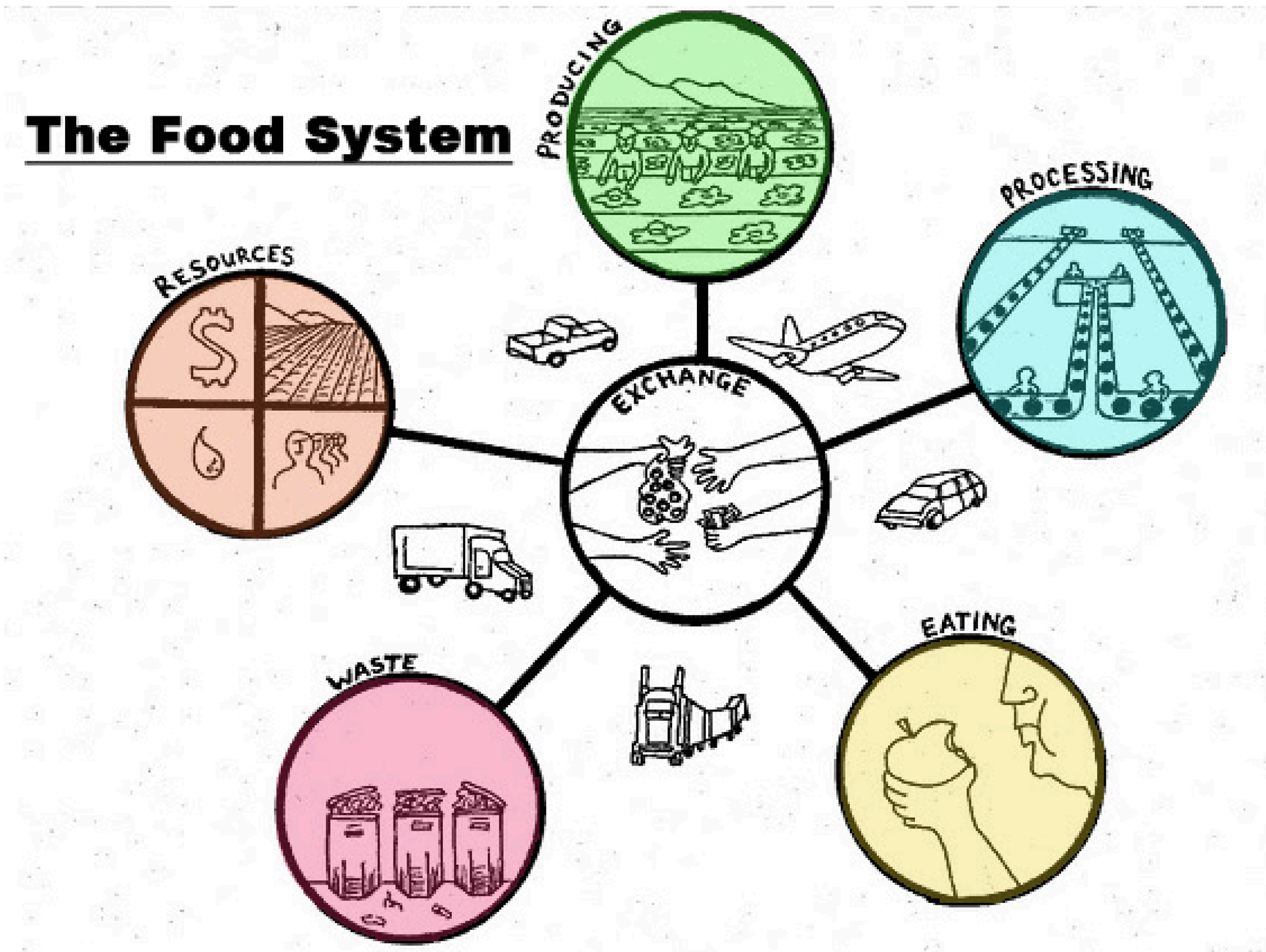

Figure 1: A diagram of the different components of the food system. "The Food System" by Hunt041, CC BY-SA 3.0.

One of the most important systems in our society is the food system. Crops, such as vegetables and cereals, form the base of the food system because they are grown to be sold, processed, or fed to livestock. The food system also includes water and energy consumption, food processing, transportation, retail, and human health (Ericksen, 2008). Despite our huge industrialized system of perfectly engineered farms, about two billion people are still malnourished and about 50 million people in the US alone experience food insecurity (Ziska, 2017). There is plenty of food to go around but it often is not distributed evenly, with much of it going to waste before it is purchased or even thrown out for not looking "good enough". These devastating figures of starvation could increase soon as our current food system is harmed by climate change.

The history of the food system is important in understanding how vulnerable it is to climate change. In the past, farmers were limited to the preexisting nutrients in the soil. Crops needed to be rotated yearly because they each depleted different nutrients out of the soil and eventually were unable to grow there. This changed when Fritz Haber developed a way to create ammonia. He used high pressure and temperature to combine nitrogen in the air with hydrogen, now called the Haber-Bosch process (Ziska, 2017). This process is used to create fertilizers and requires the burning of fossil fuels, which contributes to climate change itself. With extra nutrients, plants grew exceptionally large but ended up falling over, reducing the yield. This led Norman Borlaug to identify special varieties of plants that did not fall over and were resistant to diseases (Ziska, 2017). From this point on, farms specialized in singular species of crops rather than planting a diverse group of them. This method works; however, if a disease or invasive species is introduced that can kill one plant in the field, then the entire field will be compromised since the plants all have the same weaknesses.

Climate change has the potential to harm all aspects of the food system but the most direct impacts of climate change on the system will occur in food production. These effects are expected to be widespread and complex. Theoretically, rising atmospheric concentrations of CO_2 could increase crop yields since CO_2 is an essential nutrient needed for plant growth; however, other factors such as temperature and limited access to other nutrients could counteract these benefits (EPA, n.d.). Furthermore, the same factors which could increase crop yields would also allow weeds to thrive and choke out the desirable crops. Rising concentrations of CO_2 are also linked to a decrease in protein levels of grains and potatoes, lowering their nutritional value and thereby increasing the amount necessary to maintain a healthy diet (Vermeulen et al., 2012). Another way in which climate change will affect crops is through the increased frequency of extreme temperatures and weather events. As technology has improved, crop yields have consistently improved

as well, leading to fewer farms producing a larger portion of the food supply (usually with only one crop each). Extreme weather events such as droughts and floods pose a serious risk to our food system because they can significantly harm crop yields, as demonstrated by Figure 2. As climate change continues extreme weather events will only continue to worsen in both frequency and severity causing increased variability and uncertainty within the crop production system.

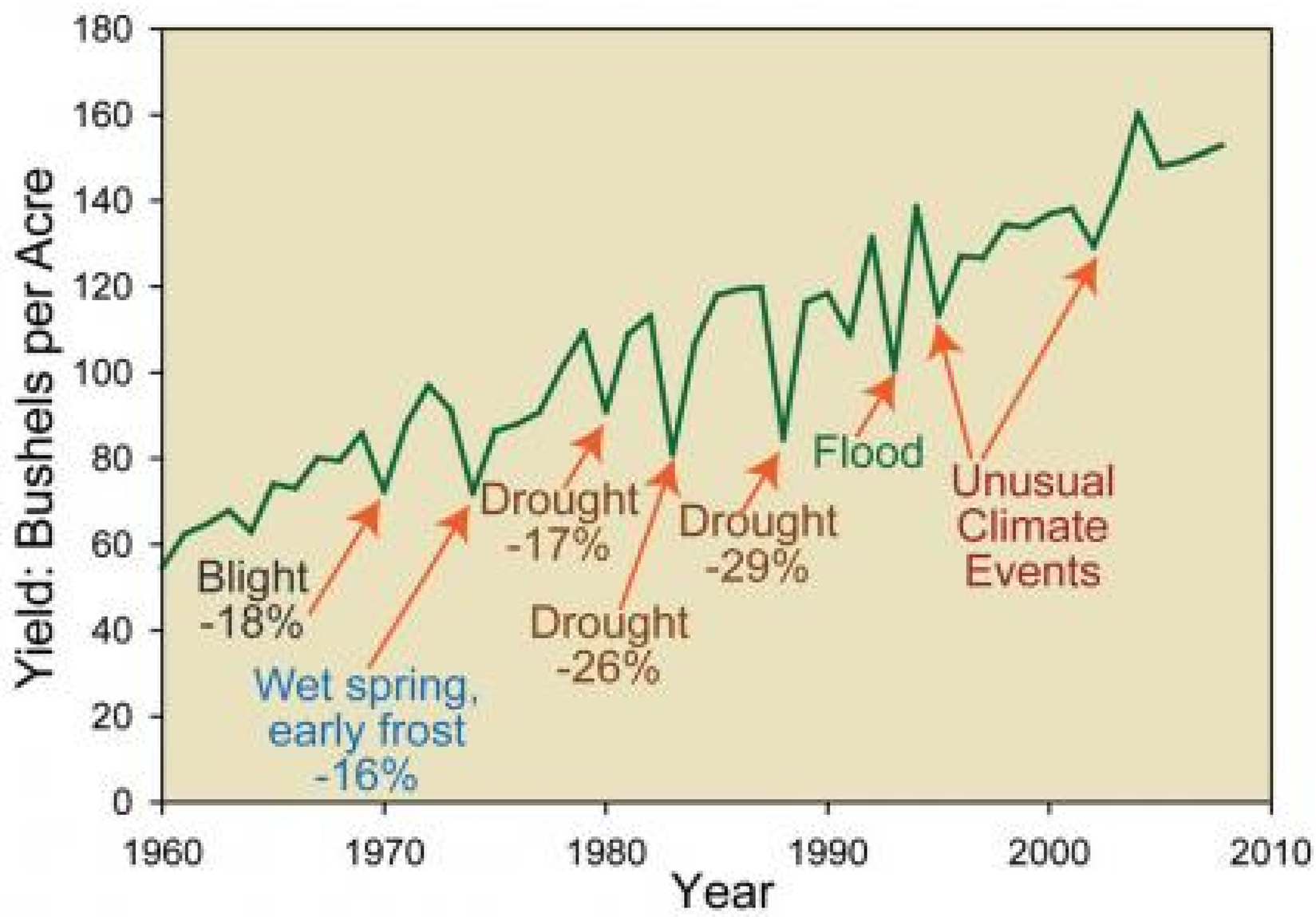

Figure 2. This graph displays the average yield of corn in bushels per acre from 1960 to 2008. It also displays some extreme weather events and their effect on crop yield in that year. "US Corn Yields from 1960 to 2008", U.S. Global Change Research Program, Public Domain.

Livestock is also threatened by climate change. Heat waves, which have been increasing in recent years, pose a serious threat to the well-being of animals because over time heat stress can increase vulnerability to disease and reduce fertility in animals (EPA, n.d.). Other impacts of climate change also have large ramifications on livestock; for example, droughts will likely have a twofold effect.

Firstly, when there is a drought there is less water for animals to drink, and secondly, droughts also effect grain production and grass growth, decreasing the amount available for feeding livestock (EPA, n.d.). The rising CO_2 levels that are affecting the nutritional value of crops, will also affect livestock because the grains that they are fed will be lower in nutritional value and thus they will need more food to continue getting sufficient nutrients. Thus, creating a feed positive feedback loop.

The third sector of food production, fisheries, has similarly been affected by climate change. As oceans warm, many species of aquatic life are steadily migrating northward in search of cooler climates (EPA, n.d.), impacting human's abilities to collect fish, along with causing many potential harms to the already established ecosystems these fish are moving to. The warming ocean is also causing disease outbreaks in many of the species of marine life humans rely on as part of our diet. Furthermore, the acidification of the ocean is causing serious harm to many species including shellfish, where rising acidity is causing the weakening of their shells (EPA, n.d.).

Beyond the impacts on food production, climate change is expected to have many secondary effects as well. Extreme weather events pose a major threat to food storage infrastructure. As temperatures rise, the perishability of food will increase, making cold storage more essential for the storage and transportation of meats and fresh produce. The prices associated with this cold storage are also likely to rise as climate change worsens (Vermeulen et al., 2012). This includes transportation via truck, boat, and train. Many rivers will cycle between floods and droughts making those shipping routes extremely difficult and unreliable, an effect that has already begun to arise across the world (EPA, n.d.). Furthermore, the melting of permafrost will put many roads and land shipping routes, that rely on the permafrost layer being intact, in jeopardy (Vermeulen et al., 2012). Transportation of food will become increasingly variable and expensive as climate change continues.

Because of the effects of climate change, prices are going to increase, there will be a decrease in food security, food will lower in nutritional value, and food will be more susceptible to bacteria and diseases that could pose a risk to the humans.

As climate change affects the food system, the food system is also degrading the global climate. In 2014, the USA moved over 500 million tons of grain across the country. It was transferred mostly by train (25%) and by truck (61%). Since trucks and trains use a substantial volume of fuel to run, they emit a significant amount of greenhouse gasses (GHG) into the air. The average truck emits 16.8 grams of CO_2 per ton-mile, while food travels around 1000 miles via trucks (Mathers, 2020). Therefore agriculture-carrying trucks produce 5.1 million tons of CO_2 each year in the USA alone. One way to decrease the emissions caused by transportation is to buy local produce. Buying a head of lettuce that traveled hundreds of miles to the supermarket, uses a lot more carbon than the relatively few miles needed to travel to a farmer's stand. This change however can only go so far. Since there is very little space for farmland near the city, millions of people living in urban areas don't have the option of buying local. Some food will still need to be transported large distances to support everyone. But if there was more local produce available (home gardens or local farms), the total transport emissions could be cut down.

Just as significant in the food system's contributions to climate change is the clearing and destruction of ecosystems. This can come in many forms, from deforestation, to the poisoning of soil and water. Deforestation happens because as farmers want to expand, they must clear new spaces which already has other life occupying it. By doing this, farmers are destroying the habitats of the plants and animals living in the forest. At the same time, it is putting more carbon into the air. Most plants (especially trees) sequester carbon throughout their life and release that carbon when they die. Decomposers will break down the dead plants and the gasses inside the cells will be released back into the air. This is most evident in the

Amazon Rain Forest where four million acres have been cut down for farming (Gibbens, 2019).

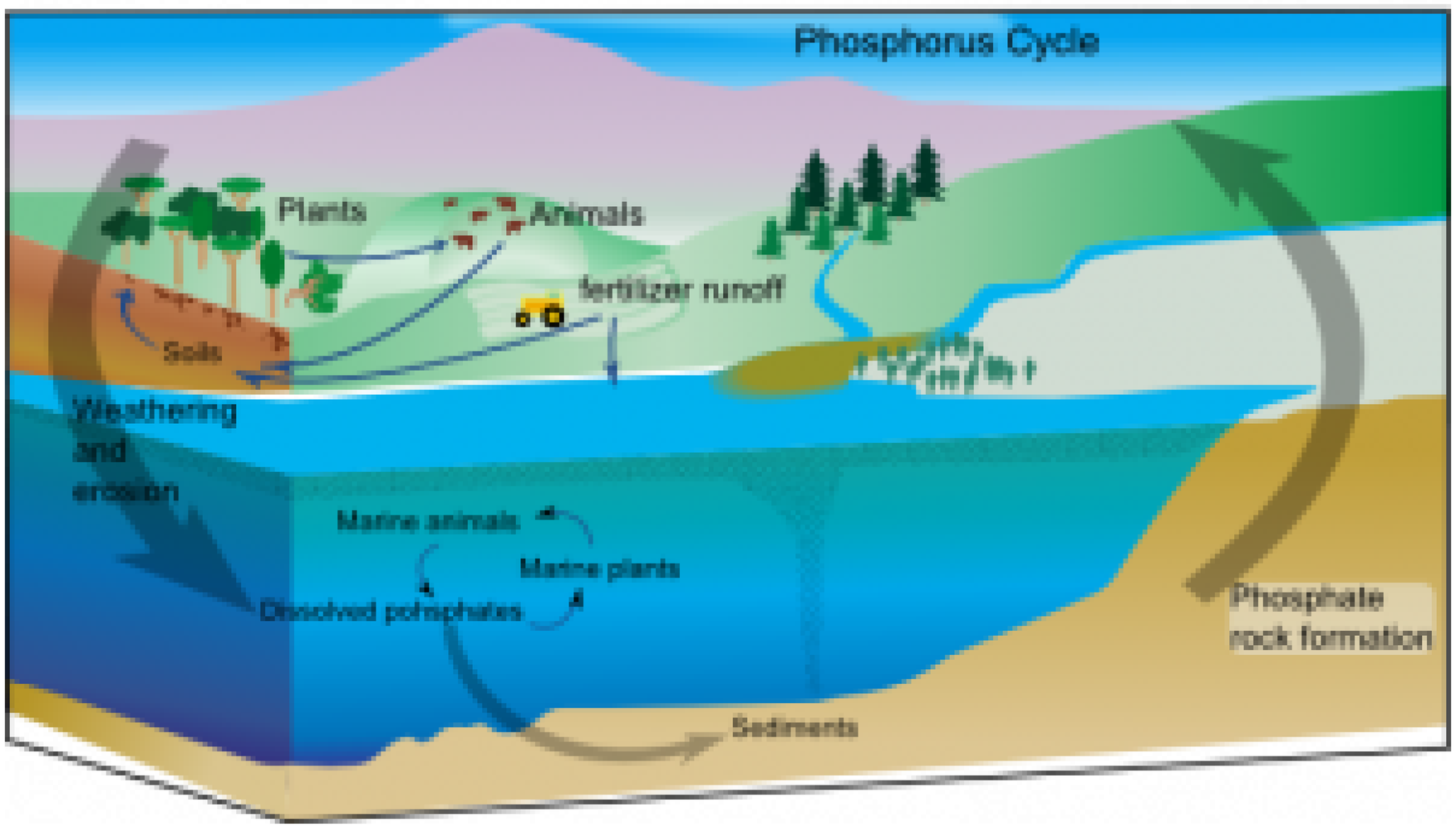

Figure 3:A diagram of the path that the phosphorus in fertilizer takes and the ecosystems that are affected. "Phosphorus cycle" Reworked by Bonniemf from the public domain file File:Carbon cycle-cute diagram.svg, CC BY-SA 3.0.

Additionally, once the plants are planted, they are often fertilized with inorganic fertilizer. When these fertilizers are put into the ground, the plants absorb the phosphorus, nitrogen, and heavy metals that are in the fertilizers. Animals eat these metals and get sick while also spreading them. This causes negative effects to local ecosystems (Savci, 2012). The excess nitrogen and phosphate get washed into rivers, wetlands, and underground water supplies (Figure 3). Intuitively this may not seem bad since humans give plants these nutrients but in large quantities there are serious environmental hazards. This is because if excess phosphorus is added to a body of water, the number of algae increase exponentially. This process is called "Eutrophication" (Ayoub, 1999). As the process continues, the algae use all the oxygen in the water, eventually suffocating all the life in that body of water (Bishop, 2015).

Additionally, the nitrogen, even at very small amounts, makes the water toxic to plants and animals (including humans). This makes farming harder since the local water needs to be treated before use.

There are many different approaches to prepare for the future which include buying more land and using more fertilizer, but these do not help the environment or protect it. To truly plan and adapt to the changing climate, new farming policies, infrastructure, and education efforts must be made. This is to ensure that farms and the whole food system can be sustained and better protected. As of now in the USA, the USDA (United States Department of Agriculture) has put forward recommended solutions to potential problems that will be occurring in upcoming years. This includes changes in precipitation, soil nutrient depletion, stronger droughts, and overall variance in growth conditions.

One method to keep farmers from cutting down forests for more land would be to pay or incentivize farmers to keep forests. This could be achieved by paying farmers not to cut down forests and or helping improve efficiency of farms via sustainable methods. The funds to protect the forests could come from governments or companies that want to protect the environment. Another way to protect farmers is to implement a crop insurance system that would limit the uncertainty of income for a given year. This would allow farmers to always earn something even if their crops fail for a year. It would no longer be a necessity for farmers to expand their land to survive. With the financial relief farmers would not be driven by necessity to expand and that they are rewarded for not expanding they can work on resource efficiency instead.

The primary goal of this efficiency is to decrease the negative impact of fertilizers on the surrounding area. A way of achieving this is via water management systems. They can be installed to decrease the run-off of fertilizer, specifically phosphorus, into the surrounding environment. One way to do this is to use a system called “drip-irrigation”. This slowly drops water into the soil and

fertilizers can be applied more effectively to the plants (Shock, 2014). This makes fertilizer more efficient and less water is needed. One downside to this process is that it is expensive to install and requires more maintenance than standard irrigation. However, with increasing support from the public and government, this is could be a viable method for limiting climate change while increasing the efficiency of farmer's land. This will not be enough on its own, however. As the planet moves towards environmental sustainability, there are many different factors at play and the food system is one of the more important ones.

Figure 4. This is drip irrigation. The hoses carry water and fertilizer right to the base of the plant and slowly let water out. "Drip irrigation in Lemo" by africarising, CC BY-NC-SA 2.0

If our current agriculture system fails, not everyone will be affected equally. As with many other issues in our society, those with less money will be harmed the most. People living in poverty already experience food insecurity and constantly wonder when

they will be able to eat next. Even with steady jobs, many people still live paycheck-to-paycheck, struggling to afford enough food for their growing children. Many of these people reside in urban areas that lack proper updated infrastructure and have poor resources such as inadequate supermarkets and limited options. When climate change leads to big decreases in food production, the prices will rise drastically, expanding food insecurity to millions more people (Wheeler & von Braun, 2013). Shortages in stores would also occur as people stock up and hoard food in fear of not having access to any at all. Subsequently, severe inflation would drive up prices even more, making the poor poorer and the rich richer as they profit off other's struggles, widening the social gap.

People of different races would also be disproportionately affected by climate related changes to the food system. As of right now, a higher percentage of people of Hispanic or African backgrounds face food insecurity in the U.S., expressed in Figure 5. This divide would only be exacerbated by climate change because Hispanics and African Americans are offered less access to support and resources in their communities (Silva, 2020).

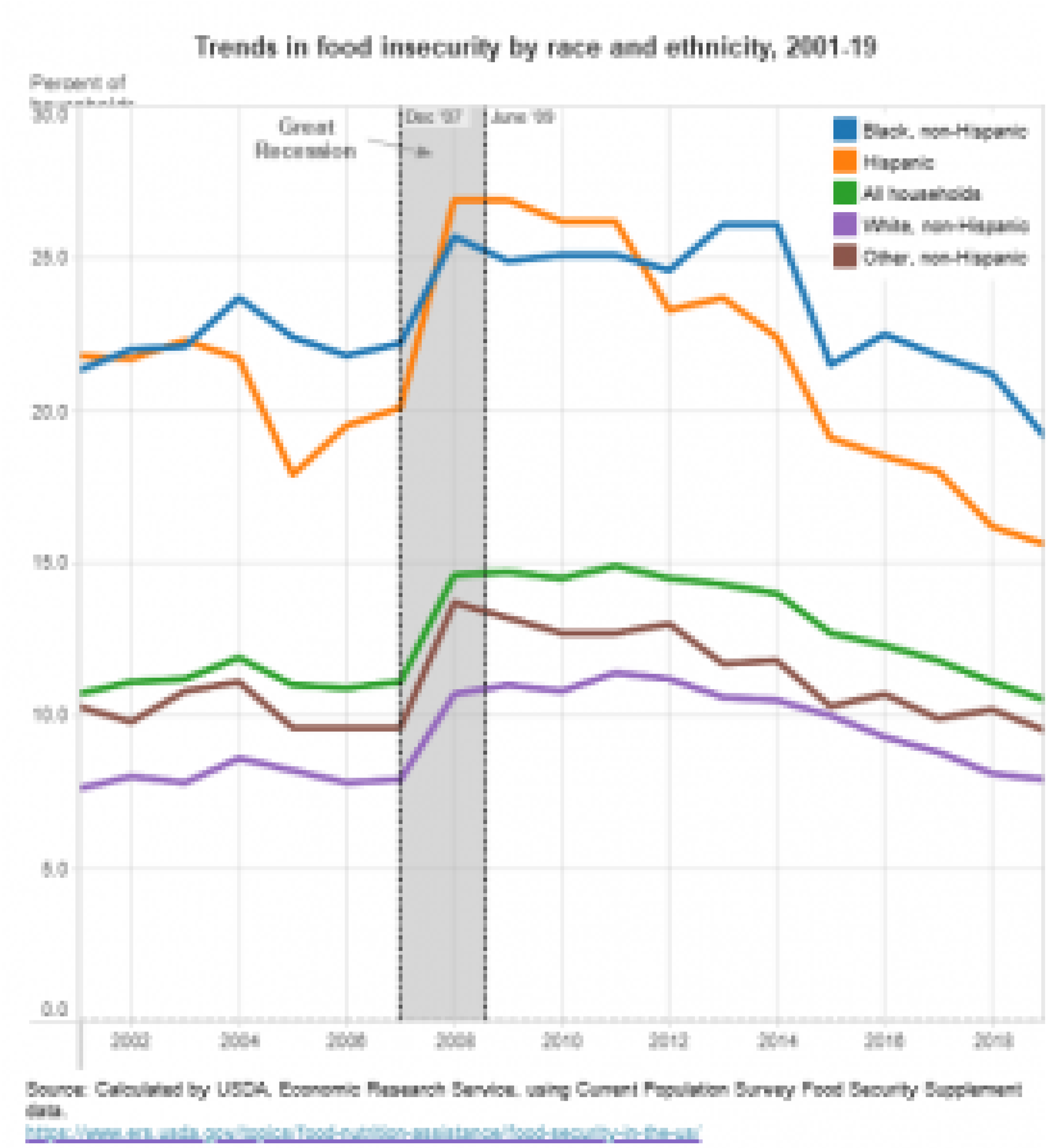

Figure 5: A graph depicting the percentage of the U.S. population which is food insecure by race from 2004 through 2019. "Trends in food insecurity by race and ethnicity, 2001-2019", USDA, Economic Research Service, Public Domain.

Food availability also varies by region or country. Recently the countries suffering from the most starvation and malnutrition are in Southern Asia or sub-Saharan Africa. Studies and models predict that food will only become scarcer in those regions as climate change harms food production. Figure 6displays this imbalance of change, showing how most industrialized northern regions will maintain a good production of food while developing southern

regions will see big decreases in crop yields by 2050. Africa and South Asia are predicted to experience an average decline in crop yields of about 8% by 2050 (Wheeler & von Braun, 2013). Differences in how climate change effects various regions are due to the preexisting diseases, invasive species, and patterns of rainfall and how susceptible these factors are to climate change. It's very clear that new operations of growing, processing, and distributing the food supply need to be implemented soon in order to prevent these vulnerable regions from seeing even more starvation and malnutrition.

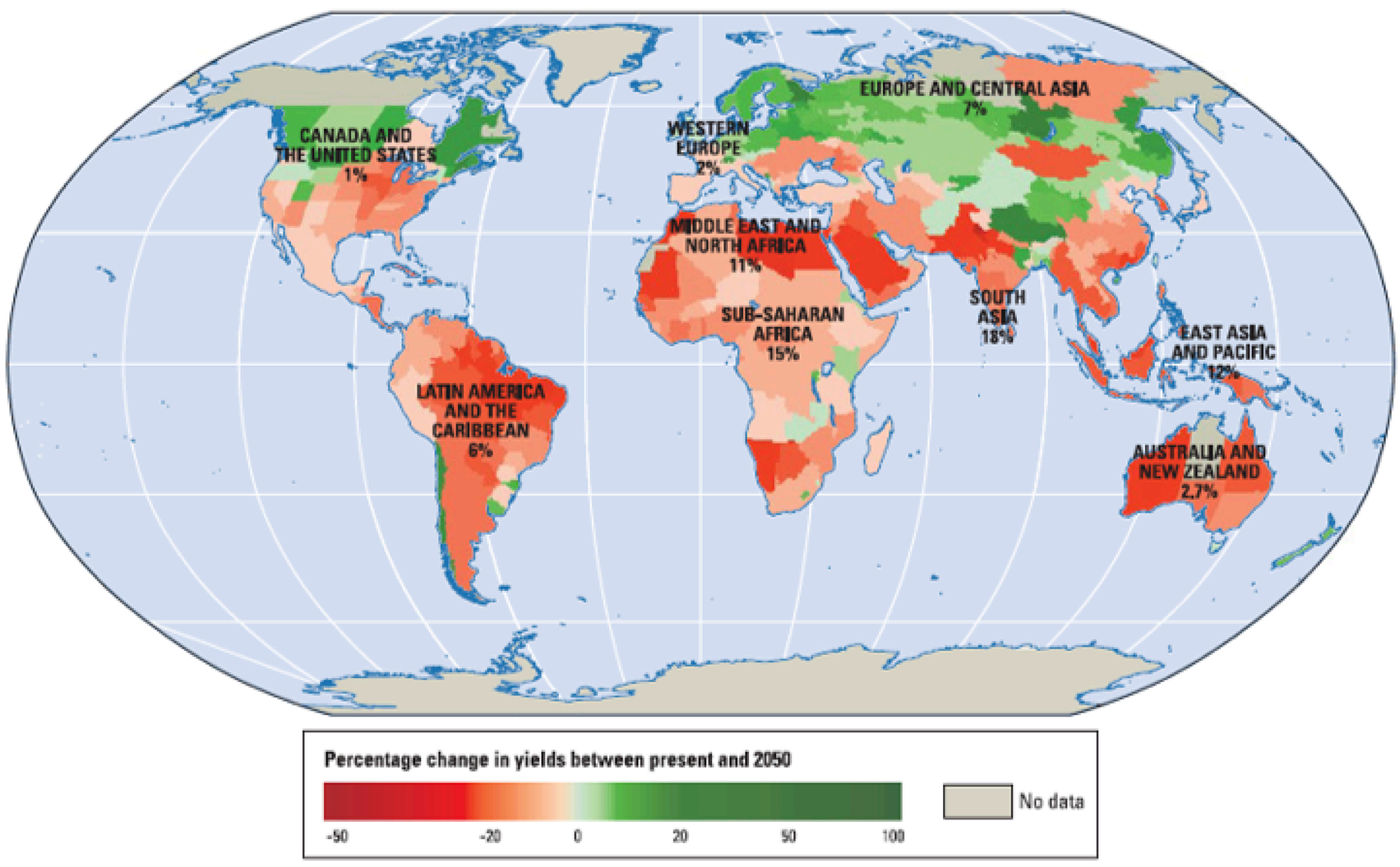

Figure 6: This map from 2010 displays the expected changes in crop yields due to climate change by 2050. The data is comprised of changes to eleven different crops that, together, form a net change in total crop yield that is meant to represent all crops in the area. World Bank. 2010. World Development Report 2010 : Development and Climate Change. Washington, DC. © World Bank. https://openknowledge.worldbank.org/handle/10986/4387, CC BY 3.0 IGO

Human health around the globe relies heavily on food accessibility. Many factors of climate change can harm individual health, but changes to food are arguably the most impactful. Damage to the food system caused by climate change may leave

many people with no access to certain key food groups that are essential for nourishment and well-being. Depending on where someone lives, they may not be able to buy fruits, vegetables, grains, or meat. High quality, nutrient dense foods may be in short supply as well, leaving undesirable and non-nutritious foods as the only option for most people. One study estimates that by 2050, the consumption of fruits and vegetables will decrease by 4% and consumption of red meat will decrease by 0.7% (Springmannet al., 2016). These global diet changes could result in about 529,000 extra deaths related to climate change each year. Although the change seems small, the health impact takes a large toll on our bodies. This same study predicts that if we could reduce human contributions to climate change and find new ways to produce our food, there could be a decrease in climate related deaths of at least 29% (Springmannet al., 2016). Therefore, figuring out solutions to these future problems is crucial. 2050 is not that far away so we need to adapt our food infrastructure immediately to save thousands of lives and prevent suffering before it is too late.

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6. The Societal Impacts of Climate Change on Water Resources

By Katherine Corbin, Elizabeth Dalberg, and Gabriel Ward

Climate change has had a great impact as water resources affect society. The hydrosphere has absorbed excessive amounts of CO_2, and water has been polluted by different micropollutants. Water scarcity and droughts have also had a large societal impact (Leahy, 2018). If water becomes scarcer in agricultural regions, food supplies will also be threatened, and countries will need to start rationing water. Groundwater resources have also been affected by the increased melting of glaciers in the cryosphere, which will eventually lead to less drinking water for communities surrounding mountain ranges. The pollution and scarcity of these resources are having negative implications for other communities such as Cape Town, Barcelona, and São Paulo. However, there is still hope for water resources. Innovations in nanotechnology can be used to remove pollutants from these water resources. This cost and time effective resource could possibly save water resources and lessen the impacts that climate change is having on society.

Introduction: Climate Changes Impact on Water Resources

As evidence of climate change becomes increasingly abundant, one critical aspect of our lives that will be affected is our water resources. These resources are greatly impacted by pollution caused by climate change. Glaciers have already seen massive decreases in net mass, putting many communities that rely on melt water from these glaciers to put at risk of losing their drinking water. In addition to this, many desert regions have been affected by the loss of water. Droughts are increasing and many regions have been experiencing shortages of water (Figure 1). The limitations of water have also affected the agriculture production which countries rely on for their economy.

Water Scarcity

Regions around the world are facing water scarcity and droughts. Cape Town, South Africa, is in a water crisis because of a severe three-year long drought which has caused water to be rationed. Cape Town is at a point where they have reached "peak water". This means that they have safely reached the amount of water that can be taken from the area. If the drought persists, Cape Town will reach "day zero" when millions of homes will have no running water (Leahy, 2018). The regions rely on the stability of the climate water cycle. Climate change has disrupted the Earth's water cycle affecting how much rain falls, where it rains, and when it rains. The atmosphere is warming the planet, which is increasing the absorption of water from the soil. The absorption of water is affecting regions where rain belts and deserts have shifted and changed the amount of water for each region (UCAR Center for Science Education). In 2015, São Paulo, Brazil reached its own "day

zero", where they had to shut off water systems for 12 hours forcing businesses and industries to shut down (Leahy, 2018). The atmosphere is absorbing water faster than the water cycle can produce enough water for Brazil's economy to function. Barcelona, Spain in 2008 had to import freshwater tanks from France. All over the world people are experiencing more frequent water scarcity and droughts because of climate change (Figure 1). In the southwest of the United States, increasing droughts are creating more wildfires and affecting livestock and crops. The warming temperatures will evaporate the water that is left in the ground creating drier soil, and worsening wildfires (Center for Climate and Energy Solutions, 2020). The increase of carbon dioxide and water vapor in the atmosphere has warmed the Earth and shifted the rain belts. The regions that do not have the rain belts are seeing an increase of water absorption from the soil, and no rain to stop the soil from becoming dry. This is happening a lot in Eastern Africa, Southwestern United States, Australia and many more places (Figure 1).

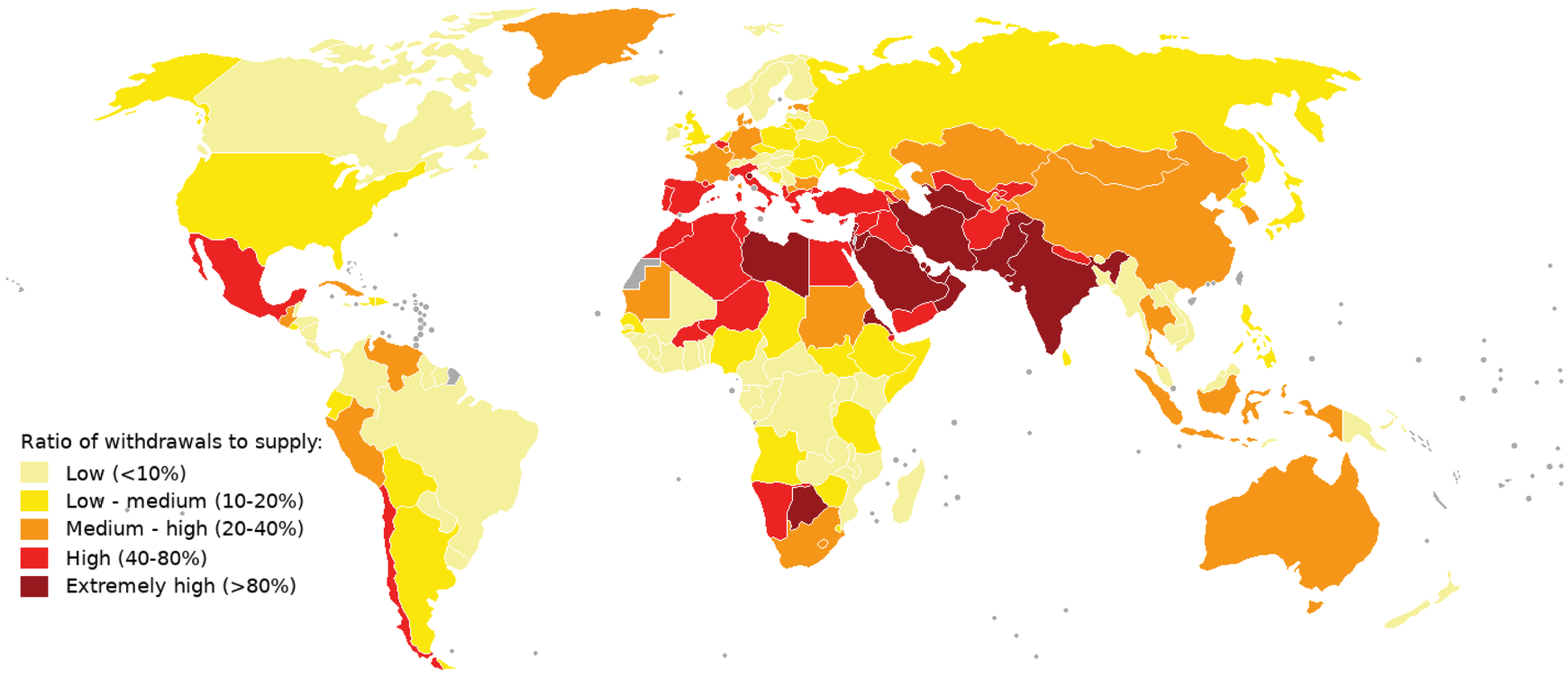

Figure 1. A map of the world showing how often specific regions of the world have water stress during the year. "2019 water stress map", Genetics4good, GNU Free Documentation License, Version 1.2.

Solutions for Water Scarcity

Crops will be more tolerant to heat and water stress, and soil management practices will lead to higher quality soil retention (Marshall et al., 2015). A simple solution to this problem, is to grow water intensive crops in water intensive regions, and vice versa. Water intensive crops need tons of water to be able to grow and produce. A possible solution to water scarcity is reusing treated wastewater. This has shown to be a cost-effective solution (Leahy, 2018). Other short-term solutions to stop water scarcity are conserving water, more efficient water usage throughout industries, alternative water supplies, adding in green infrastructure for stormwater management, and having plans in place for water in emergency droughts. A more suitable and longer lasting solution, however, would be to curb greenhouse gas emissions (Center for Climate and Energy Solutions, 2020).

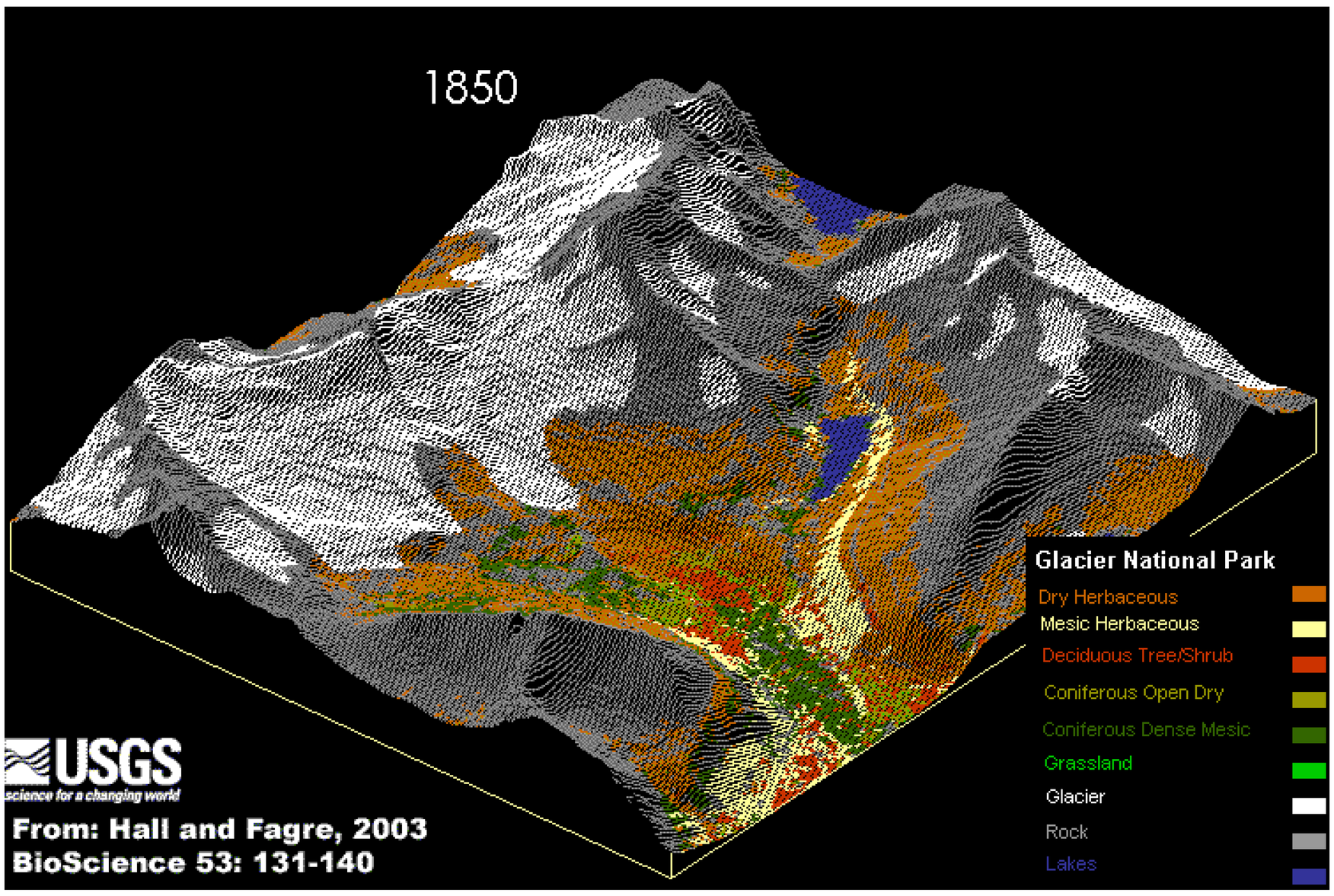

Figure 2. A gif showing the past and projected melting of glaciers in Glacier National Park, located in the Rocky Mountains. "Animation of Modeled Climate-Induced Glacier Change in Glacier National Park, 1850- 2100". Hall & Fagre (2003), USGS, Public Domain.

Melting Glaciers

In addition to African and other desert communities experiencing increased droughts, communities surrounding mountain ranges will be subject to significant changes in their water supply. These changes are caused by the increasing loss of mass in glaciers located around mountain ranges such as the Himalayas, the Rocky Mountains, and the Andes. In a study analyzing the effects of increased glacial melt in the Rocky Mountains, glaciers have lost 259 +/- 28 Gt/yr from 2003 to 2009. 78% of the meltwater produced from these glaciers flows west of the mountains into the Pacific Oceans, while the remaining 22% flows east into the Arctic Ocean and Hudson Bay. This contributes to about 0.72 mm +/-0.08mm sea level rise per year (Castellazi, 2019). Projections for the future raise some significant concerns, as by the next century it is predicted that glaciers in the Canadian Rocky Mountains will have lost 90% of their mass (Castellazi, 2019). Figure 2 displays past glacial ice melting as well as projections for the future in Glacier National Park, located within the Rocky Mountains in the US. The impact this will have on communities surrounding these mountain ranges is extremely difficult to predict due to the complexity of groundwater and surface-water interactions. Monthly discharge projections range from 23% to 518% of current discharge amounts from glaciers (Buytaert et al., 2009). This extreme amount of variability is concerning, as these changes could have drastic effects that will impact the way of life in those surrounding communities, including increased flooding, damage to crops, and less snowpack, or minor effects that may go unnoticed.

Glaciers provide a reliable source of drinking water during dry periods and warm months. Glacier drainage basins cover 26% of the global land surface outside Greenland and Antarctica, which are covered in ice sheets. These basins are populated by 1/3 of the world's population (Davies, 2020). Meltwater that flows downstream from glaciers is used for various critical aspects of society that

include irrigation, hydropower, ecosystems, and of course drinking. Meltwater from these glaciers acts as a vital supplement to other water resources during droughts and low streamflow (Davies, 2020). As glaciers continue to shrink at an alarming rate, annual meltwater increases until "peak meltwater" is reached. At this point, runoff decreases since the decreased volume of the glaciers can no longer support the increased meltwater. In many basins that rely on meltwater during droughts, peak meltwater is projected to be reached in the next 20-30 years. This means that half the worlds population could be living in water scarcity by then (Davies, 2020).

Water Pollutants

Climate change has greatly impacted water resources, causing them to become polluted. Chemical pollution has had significant ramifications on water resources as inorganic and organic micropollutants including metalloids, toxic metals, and a variety of synthetic organic chemicals have polluted water supplies. The most relevant sources impacting water pollution include geogenic pollutants, mining operations, and hazardous waste sites. Pathogens are also present in these polluted waters significantly impacting human health as a lack of safe drinking water currently affects more than a third of the people in the world (Schwarzenbach et al., 2010). Water resources have also been significantly impacted by the absorption of CO_2 into the hydrosphere causing the pH levels of the oceans to decrease, making the water more acidic (Barford, 2013). The pollution of water on Earth has greatly impacted societies as pollutants and pathogens that are present in water supplies has left people without clean drinking water.

Solutions to cleaning polluted water

Fortunately, there are solutions that can be used to clean water resources, one of which being nanotechnology. Nano and micromotors can perform many forms of specialized tasks, including cleaning polluted waters. These motors can move around and mix contaminated water, increasing the interaction between active sites and target pollutants. The active sites that are present remove the pollutants that are being targeted from the water resources. This form of treatment is cost and time effective. The removal mechanisms used in nanotechnology absorb the organic pollutants, toxic metals, and oil pollutants that are present in polluted water systems. The organic pollutants are removed through degradation (Eskandarloo et al., 2017). The use of this technology will greatly help water resources leaving a positive impact on society.

Conclusion

Overall, water resources on Earth have been greatly impacted by climate change and pollution. This damage comes with a large societal cost, as these water resources play a significant role in our well-being. Water scarcity and droughts have become a large problem leading to drastic effects on the agricultural industry. Glacier melting has also impacted groundwater resources in the form of excessive discharge and an unprecedented amount of mass lost. In addition to curbing the drastic changes in our water systems, maintaining and improving cleanliness in our water supplies should be a top priority. A technology that could be useful in this nanotechnology. Nanotechnology is a cost and time effective tool that could significantly help water supplies. Water resources play an important role in society, and they should be maintained.

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7. Climate Change Impacts on Human Health

By Gabriel Espinosa, Frank Ford, and Alex Wadsworth

The rapid warming of Earth as a result of anthropogenic climate change is and will continue to have devastating consequences to the ecosystems that call this planet home. While us humans tend to see ourselves as beyond nature, truthfully, our societies and health are still heavily dependent on the cycles that encompass life. As global temperatures continue to rise as a result of greenhouse gas concentrations in the atmosphere, heat related mortality will multiply in the coming years. Habitable ranges of disease transmitting vectors such as insects will expand further from the equator, greatly impacting human pathogen infection rates. As we look to the future, nations around the world will have to adapt to the ever-expanding health impacts of climate change. Will humanity be able to keep up with the life-threatening consequences of our actions?

Climate Change and Human Health

With the widespread use of modern medicine, many health concerns of the past have become obsolete, drawing human

attention to more serious complications such as cancers and genetic disorders. However, climate change will reintroduce medical relics of the past while introducing a host of new health problems in its wake. Most literally, human health encompasses physical, social, and mental well-being and can be affected by every aspect of day-to-day life. Ideally, everyone on Earth would be physically healthy with regular exercise and access to clean food and water. Mental and social fitness is often more challenging to define but can be generalized by the ability to manage positive and negative emotions while maintaining honest relationships with others (CDC, 2020a). While all aspects of health are critical to one's survival, for the sake of brevity, the following will focus on physical consequences of climate change on one's well-being.

The stratosphere is the region above the troposphere and contains ozone which is vital to human health. Ozone acts as a barrier, protecting the surface of the earth from ultraviolet radiation by absorbing its energy and dissipating it into heat (Earth Observatory, 2009). Ultraviolet radiation is a high energy light wavelength that is emitted from the Sun, composing 10% of the total light emitted each day. However, man-made chemicals, like chlorofluorocarbons (CFC's) that contribute to climate change also react with the ozone layer and destroy ozone molecules (NOAA Research, n.d.). The depletion of the ozone layer results in a higher concentration of ultraviolet radiation reaching the surface, which can be seen in *Figure 1*, creating dangerous conditions for humans.

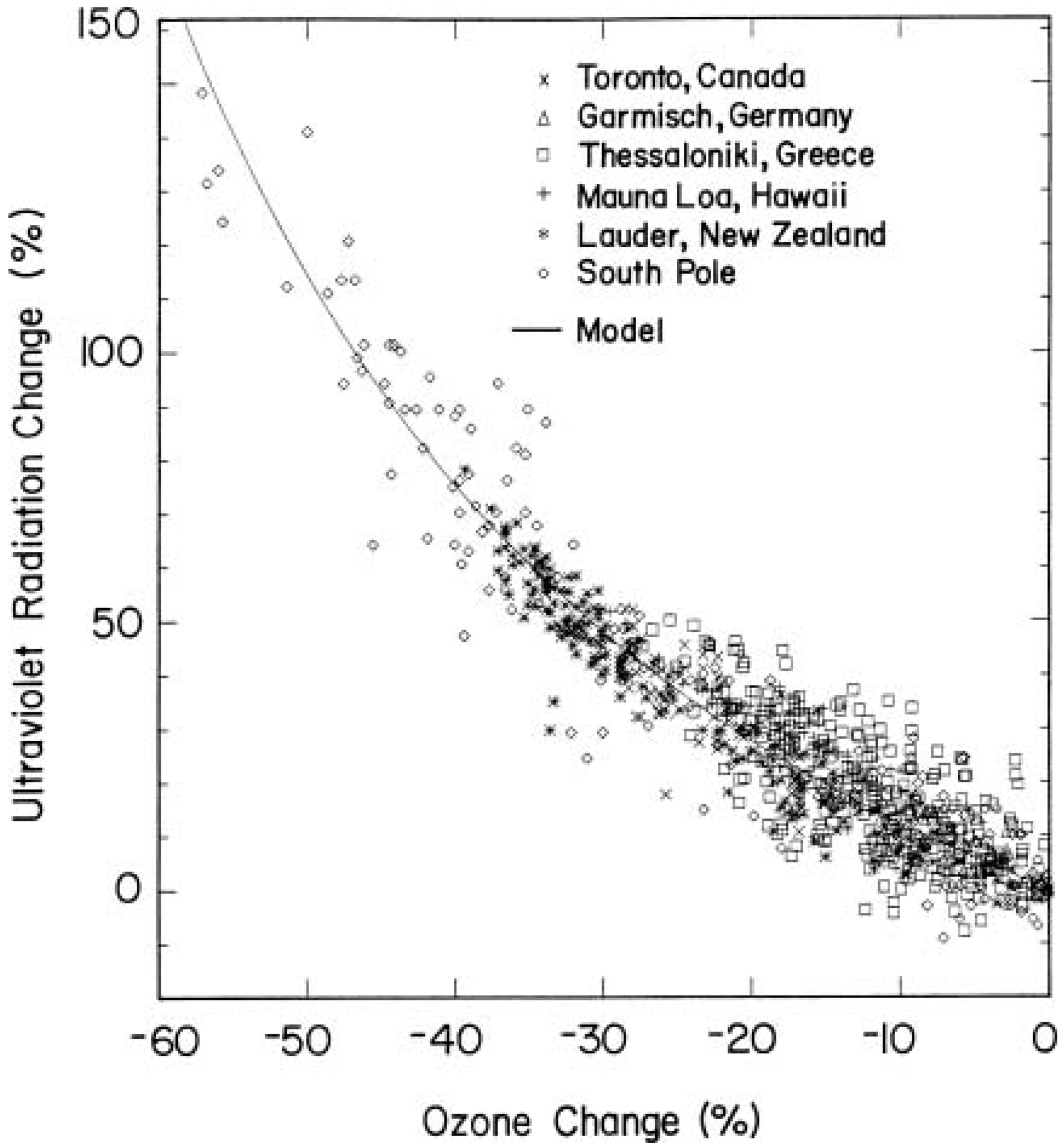

Figure 1. A graph representing the ultraviolet radiation change at the Earth's surface vs. the ozone change in the same region. As the ozone layer decreases, the amount of UV radiation at Earth's surface increases exponentially. "Increases in Erythemal (Sunburning) Ultraviolet Radiation Due to Ozone Decreases" UK Air, Air Information Resource, Open Government License (OGL)

Long term exposure to UV radiation, particularly UVB radiation, can lead to the development of cancer and an assortment of eye diseases given the skin penetrating characteristics of the wavelength (Norval et al., 2007). Given that UVB radiation can only penetrate the surface of the skin it most commonly is the cause of melanoma, a form of skin cancer affecting the pigment producing

cells below the surface. While melanoma only makes up 1% of current skin cancer cases, it is by far the deadliest, estimated to kill over 6800 people in the US by the end of 2020 (CDC, 2020b). Although the death rate of skin cancers is expected to decline as medicine improves, *Figure 2* visualizes the rapidly increasing rate of melanoma diagnoses over the past 15 years with an increase of 44,877 over the recorded period from 1999 to 2014 (CDC, 2020b). Comprehensive data on the issue hasn't fully been studied, however, scientists believe UV radiation will also have negative effects on human eyes. Ultraviolet wavelengths can cause the eyes to sunburn (photokeratitis) along with corneal swelling which can lead to severe conditions such as glaucoma and cataracts both of which can cause blindness (Norval et al., 2007).

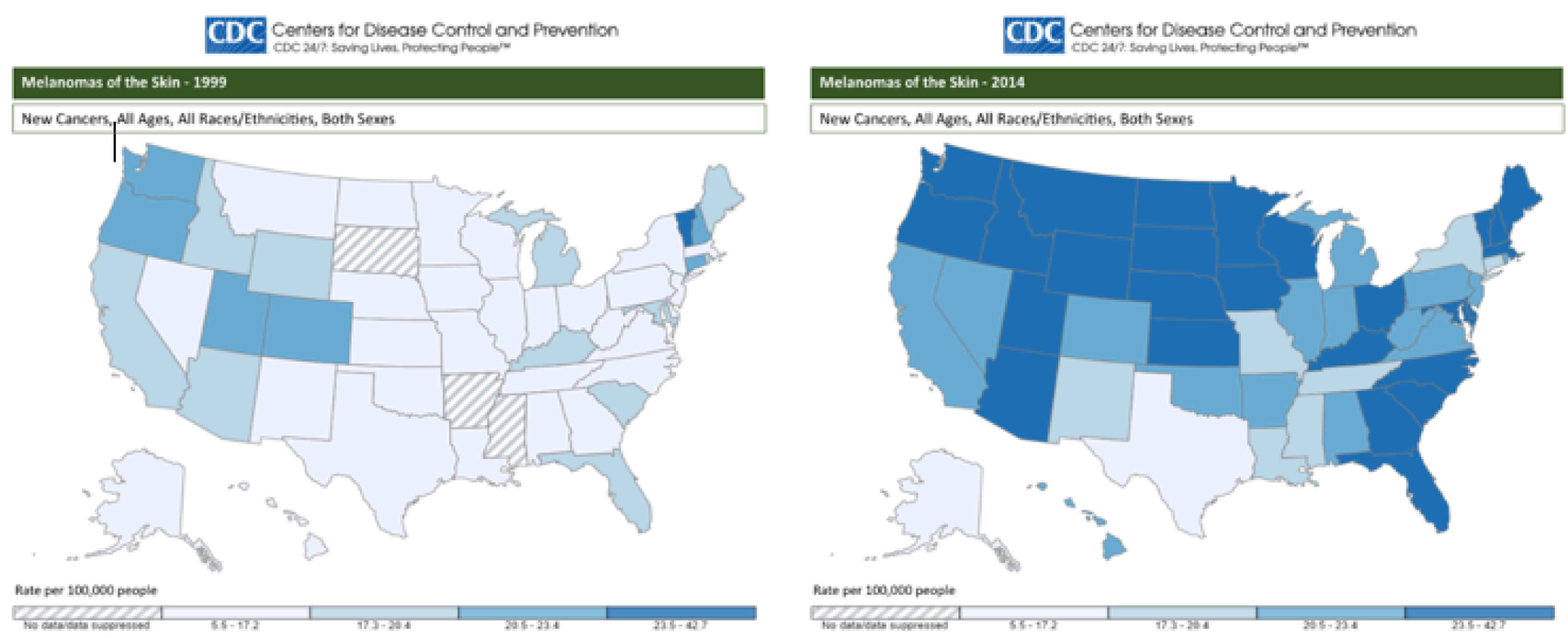

Figure 2: (left) This graph displays the cases of melanoma per 100,000 people in each state of the US in the year 1999. (right) This graph displays the cases of melanoma per 100,000 people in each state in the US in the year 2014. A clear trend towards more melanoma cases in the US over time is visible when comparing the two graphics. U.S. Center for Disease Control and Prevention, Division of Cancer Prevention and Control, Public Domain.

The troposphere, which contains atmosphere near the Earth's surface, is responsible for surface temperature, a characteristic essential to human life. In the past 50 years, average temperatures in the US have risen by 2 degrees Fahrenheit and are continuing to rise. According to the CDC, as regional and global temperatures

rise, so will the severity and frequency of extreme heat events (CDC, n.d.). Extreme heat events are detrimental to human life, shown by the 2003 heatwave in Europe which left 14,802 people dead in France alone and thousands of others in surrounding countries (Haines et al., 2006). The occurrence and concentration of heat related weather anomalies shows significant warming around the middle east and the poles which can be seen in *Figure* 3 below.

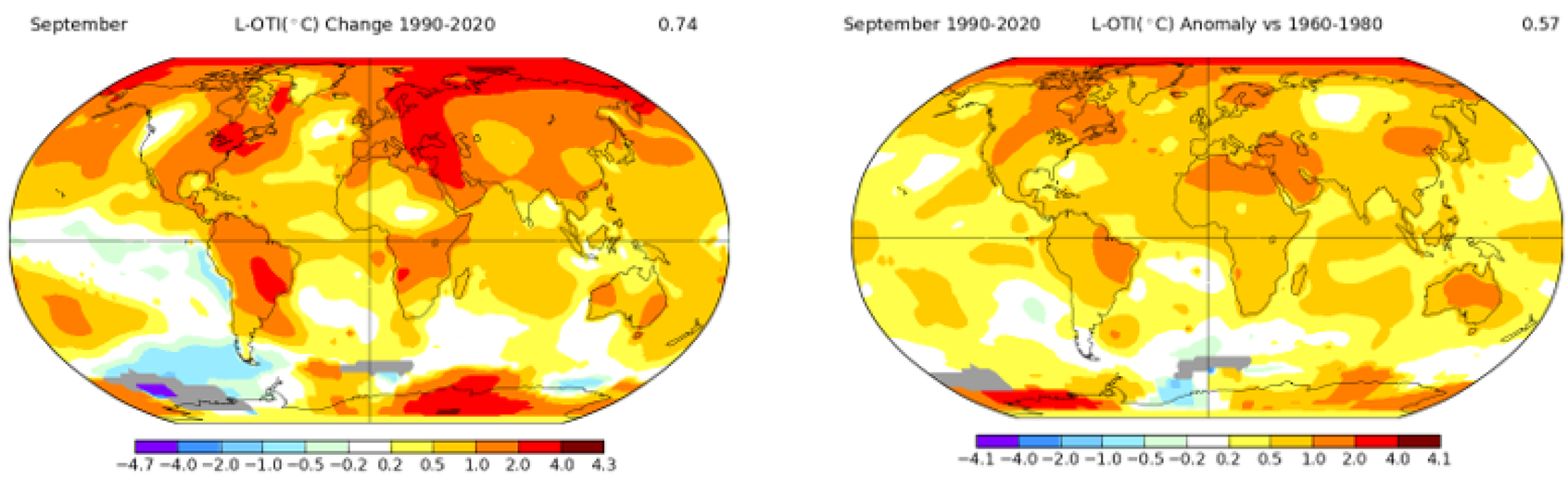

Figure 3: (left) Above is a map which represents temperature change from 1990 to 2020 where obvious warming can be seen at the poles and on the mainland of most continents. (right) Above is a map of the temperature anomalies recorded from 1990 to 2020 compared to anomalies from 1960-1980. It can be seen that the severity of the anomalies has increased by about 1 degree Celsius in some areas. The gray areas of each map represent where there is missing data. "Average surface air temperatures from 2011 to 2020 compared to a baseline average from 1951 to 1980", NASA, *GISS Surface Temperature Analysis.* (2020, *September* 13), *Public Domain.*

The described increase in global temperature will lead to a far greater rate of heat mortality around the world. Between 1998 and 2017 roughly 166,000 people died worldwide as a result of heatstroke which occurs if one's core temperature exceeds 40°C (WHO, 2020). With warmer weather, cold related deaths during winter months will decrease over time, however, deaths attributed to high temperatures will far exceed these losses, resulting in a net mortality increase due to global heat (Huang et al., 2011). *Figure* 4 below pictures the slow, yet constant trend towards higher heat mortality rates in the United States which could cost the country $141 billion in the next 80 years (Aronoff, 2018).

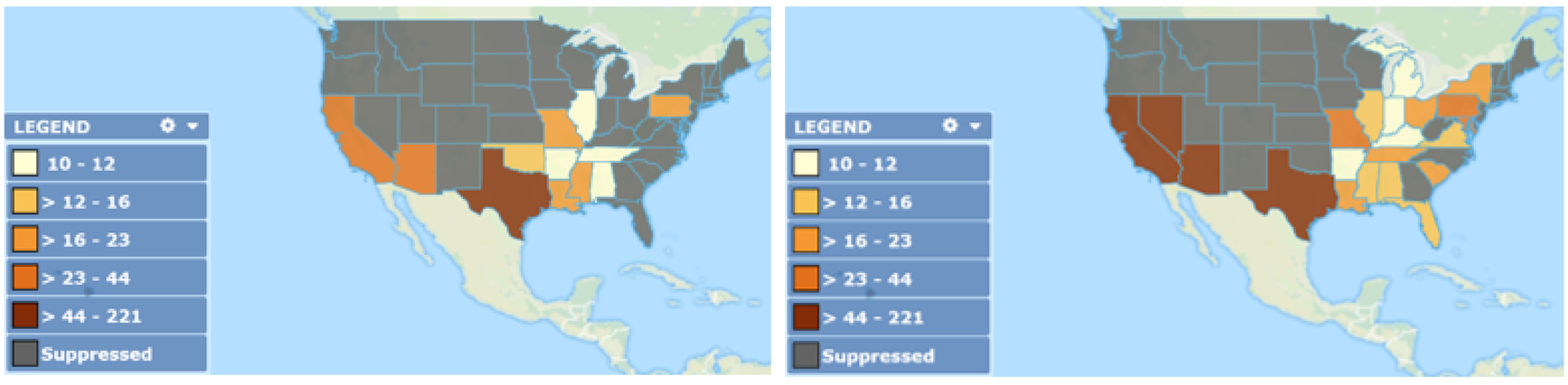

Figure 4: (left) The above map illustrates heat related mortality data in the United States in 2000 compared to (right) which plots the same data for 2018. While subtle, there is an apparent upward trend in heat related deaths. U.S. Center for Disease Control and Prevention, 2020, Public Domain.

The biosphere of Earth also plays a role on health through vector-borne diseases. Epidemiology defines a vector as any living organism capable of carrying and transmitting infections to another living creature. Disease vectors are most well known to be rodents, arachnids, insects, and parasites and their presence on this planet is increasing alongside the average global temperature (Semenza & Menne, 2009). The hosts of these diseases rely on a very warm or humid environments to survive, with an increase in rainfall promoting transmission and breeding sites (Reiter, 2001). An example of these environments is the tropics where, according to several studies which used independent data sets, they will expand up to 2 degrees in latitude (approximately 138 miles) during the 21st century due to changes in air currents above the equator (Seidel et al., 2008). This increase of the tropical boundaries will broaden the habitats of vectors and increase the human population susceptible to the viruses they transmit. *Figure* 3 shows the global temperature change over the past 30 years, illustrating that regions in North American and Europe have seen a mean rise of 0.5-4 degrees Celsius. In Italy, local transmission of *Plasmodium vivax* malaria has occurred recently, 40 years after its eradication, because of higher temperatures allowing different parasites to survive in Italy's new climate (Githeko et al., 2000). As higher temperature and humidity ranges around the equator increase, the footprint of vector-borne diseases will spread within those larger regions.

As seen in *Figure* 5, over the past 12 years the United States has seen a steady increase in insect-borne disease cases resulting from ticks and mosquitos. North American ticks are most known to transmit Lyme Disease, which, if untreated can lead to severe nerve and joint damage. From 2004 to 2016 the number of Lyme Disease cases in the US has increased by 16,625 (Rosenberg et al., 2018) making growing disease transmission a very real and current threat. Mosquito-borne illnesses have increased quite drastically in the US in recent years, from 2004 to 2015 cases peaked at 14,505 while 2016 saw a peak 47,461 cases alone (Rosenberg et al., 2018). While less common, mosquito-borne diseases such as dengue fever, when untreated, have a 20-50% mortality rate, far more lethal than tick-borne diseases (Brownstein et al., 2005).

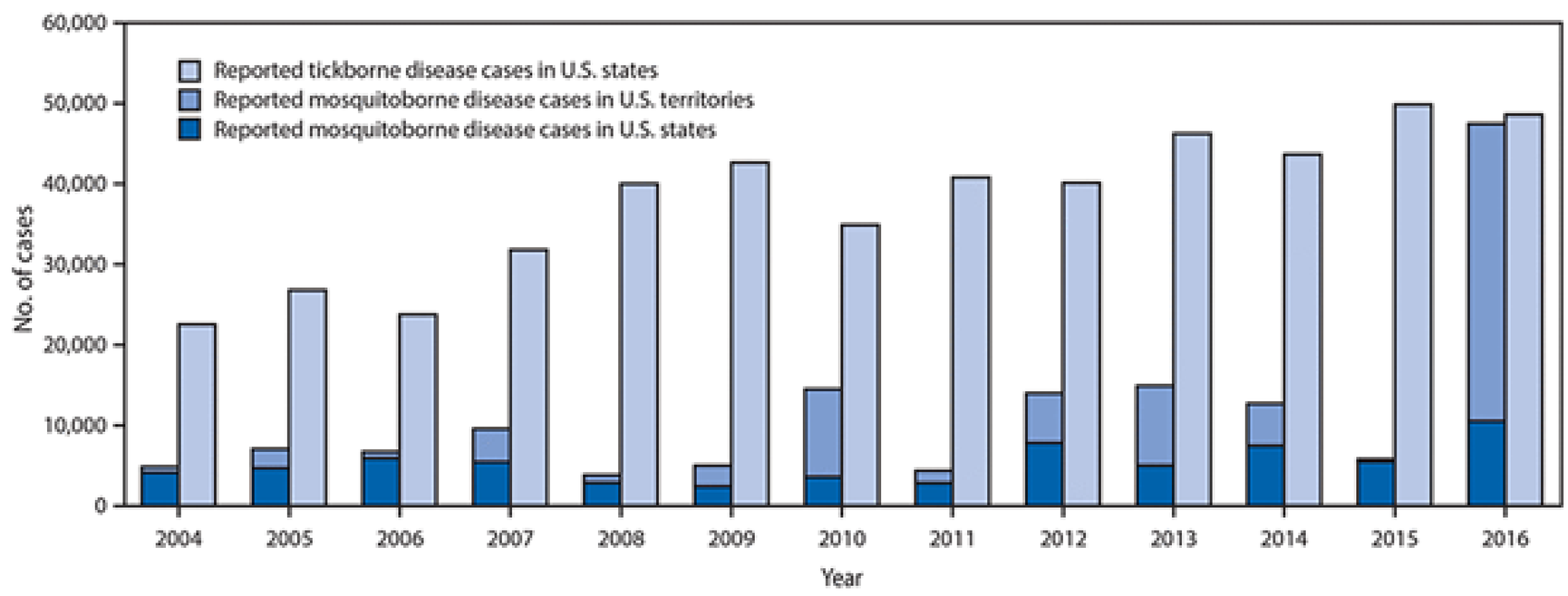

Figure 5: The above graph represents the total confirmed cases of tickborne and mosquitoborne diseases in the United States from 2004 to 2016. Although subtle and variable, a clear upward trend in yearly case numbers is displayed, most consistently in tickborne infection. "Reported nationally notifiable mosquitoborne, tickborne, and fleaborne† disease cases — U.S. states and territories, 2004–2016", U.S. Center for Disease Control and Prevention, 2020, Public Domain.*

It is important to note, the correlation between vector-borne infection rates and climate change was first characterized in the late 1990s and thus data on the matter is frequently lacking in great time scales. However, the limited data that does exist and future research prospects demonstrate convincing arguments in proving causation (Haines et al., 2006).

Previous public health research provides important insight to current public health professionals and governments so that the human population can reduce negative impacts of climate change on human health. Currently it is believed that the adaptiveness of the human population will allow for many communities to protect themselves from climate impacts, however, it must be noted that this would be a temporary buffer (McMichael et al., 2006). Additionally, human adaptiveness varies greatly depending on many factors such as geography, technological resources, wealth and governance. Research into this is being done to attempt to lessen health risks that will accompany the changing climate (McMichael et al., 2006). Furthermore, researchers are using satellite data, computer modeling, and geographic information system modelling of the effect that increased precipitation and changes in temperature will have on infectious disease (Ebi et al., 2005). This will allow for public health officials to better understand how future changes in the climate will allow for the increased spread of infectious diseases, UV concentration, and severe heat so that governments can better prepare. One final promising area that is being researched is improving case surveillance for infectious diseases (McMichael et al., 2006). By identifying highly infectious diseases faster, it will be much easier to contain them.

While currently there is highly encouraging research being done for the public health sector there is still much that needs to be done. One of the most challenging but rewarding work will be identifying how local communities will adapt to changes and what still needs to be done to allow these communities to adapt most successfully. Even though there is a good global sense of how the human population will adapt it is still mostly unknown at local levels how specific areas will or will not adapt to future climatic changes (Ebi et al., 2005). Mitigating potential future risks of these changes will need to be studied by individual communities, local governments, and nations. This challenge can be overcome, but urgency is required by lawmakers and governments so that proper preparations can take place. Without this sense of urgency there

will come a time when we reach a threshold of what the human body can endure and there will be dire consequences on humanity.

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8. Inequalities Due to Climate Change

By Jack Hanlon, Daniel Shea, Nora Smith

Climate change is a ravaging force all around the globe, constantly devastating humans in disadvantaged positions such as those in poorer countries and regions. Those who live in countries with smaller GDPs often experience greater suffering and side effects from shifts in the climate compared to larger, industrialized countries. Additionally, climate change has indirectly affected people's personal lives; for example, dryness caused by the increased global temperatures has increased the amount of hardship for women living in Africa. These inequalities play a huge role in biosphere changes, as corporations have been emitting large quantities of carbon since the Industrial Revolution, creating complications in tropical regions. Signal-to-noise ratios, variations in regional temperature compared to their average temperatures, are highest in these areas, and corporations must make large adjustments if these regions are to survive. Many of these changes are extremely harmful toward specific groups of people, as they can even leave regions uninhabitable. With so many forms of inequality found around the globe due to climate change, how can it be possible to adapt and set the world on track?

Introduction

Climate change is a relatively new field within the realm of science, and recent innovative studies often reveal new causes, drivers, and impacts of the shifting biosphere. One of the most dangerous and greatly ignored societal impacts of climate change is inequality, which strikes in a multitude of ways, such as unequal contributions to climate change's driving factors, wealth gaps, and differences in suffering. The driving factors that are disproportionately fueled by countries are highlighted by greenhouse gas emissions, but lesser factors such as plastic pollution, illegal dumping, and deforestation add up over time. Hyper-industrialized countries or regions such as the United States, China, and the European Union have accounted for over 70% of climate changing causes since the tracking of Earth's health began (Figure 1). This disparity also highlights both the extreme differences in suffering and rapidly growing wealth gaps that poorer countries experience (Figures 3, 4).

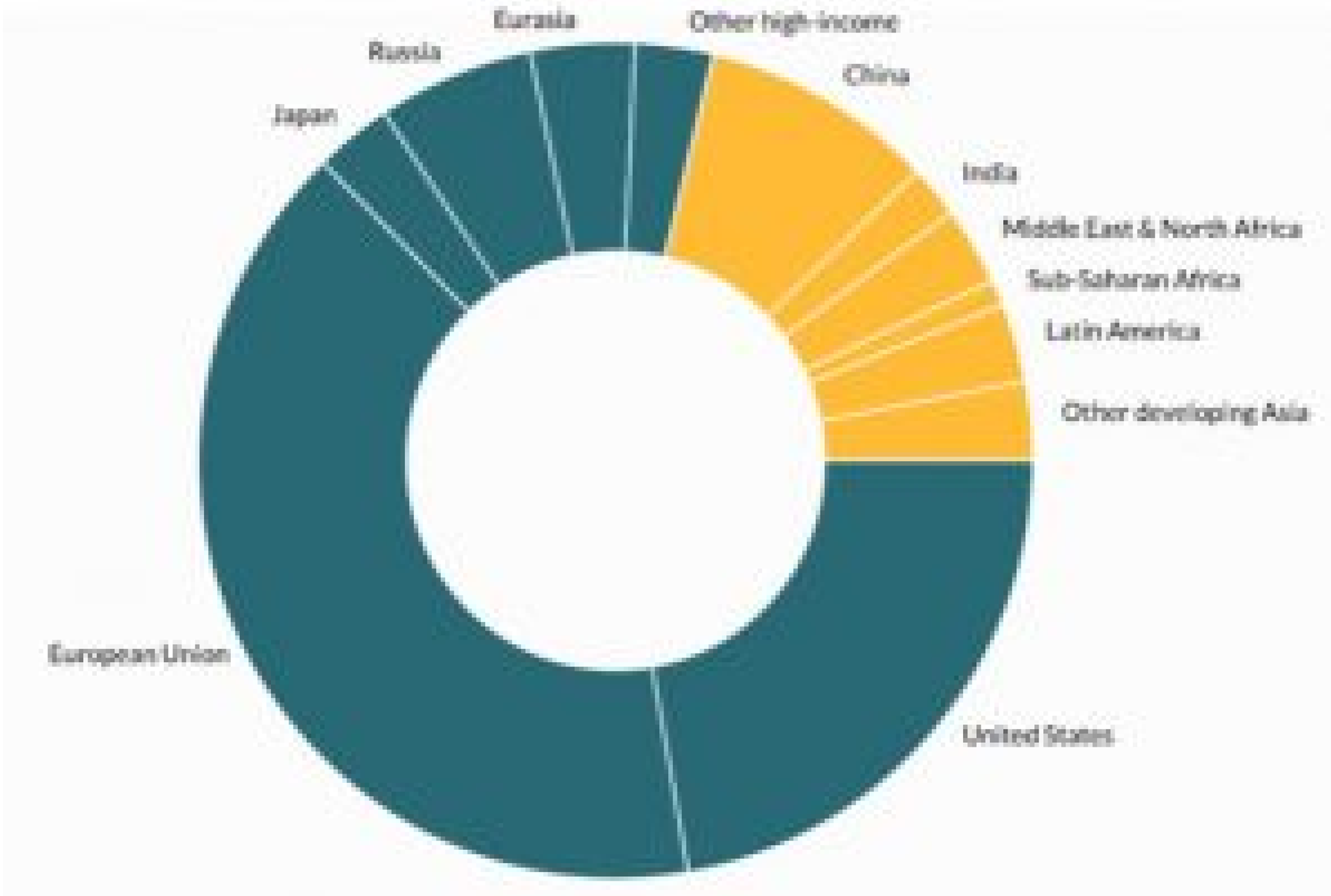

Figure 1: Pie chart representing the historical contributions to greenhouse gas emissions by country. Leading in emissions between 1850 and 2011 was the European Union, followed by the United States, and then China. Busch, (2015). "Who caused climate change historically?", Center for Global Development, Open access.

These conditions are very often overlooked, and only recently gained attention due to the 2015 Paris Agreement's covering of poorer nations and their lack of ability to respond to significant weather pattern and landscape shifts. A United Nations approved paper published later explained that "disadvantaged groups may not be able to afford such insurance and thus have to absorb the entire loss, leading to greater loss of their asset position" (Islam & Winkel, 2017). One such example is Mexico, which contributes only 1.5% of total global carbon emissions but is affected more than other Northern American countries, such as Canada or the United States. The country's National Institute of Ecology reports that more than half of Mexican states experience significant marginality and already suffered from climate-related risks, all of which has led to a loss of assets (Santelices Spikin & Rojas Hernández, 2016). Disadvantaged countries such as Mexico experience the greatest

suffering as they are the most likely to deal with climate hazards, while also lacking the means to recover effectively. These instances of inequality do not stop at Mexico, or with the highlighted factors, as a plethora of other impacts exist within communities across the globe.

Impacts

Since the significance of these impacts largely comes from where the changes in climate are most strongly felt, it becomes easier to notice when the data connects. Trends in climate change, particularly trends in global warming, have been shown to correlate with trends in gross domestic product, or GDP. Notably, the negative impacts from climate change disproportionately impact countries with lower CO_2 emissions per capita. Compared to a model without any emission-based change in global temperature, countries with less than 10 tons of carbon dioxide per capita suffered a 27% loss in GDP, while countries with 300+ tons of carbon dioxide per capita experienced a 25% growth (Diffenbaugh & Burke, 2019; Figure 2). This economic loss hits countries that already do not have the resources to properly deal with climate change, so an unfortunate cycle of financial loss is created: climate change affects poorer countries more as they cannot afford to deal with it, making them even poorer.

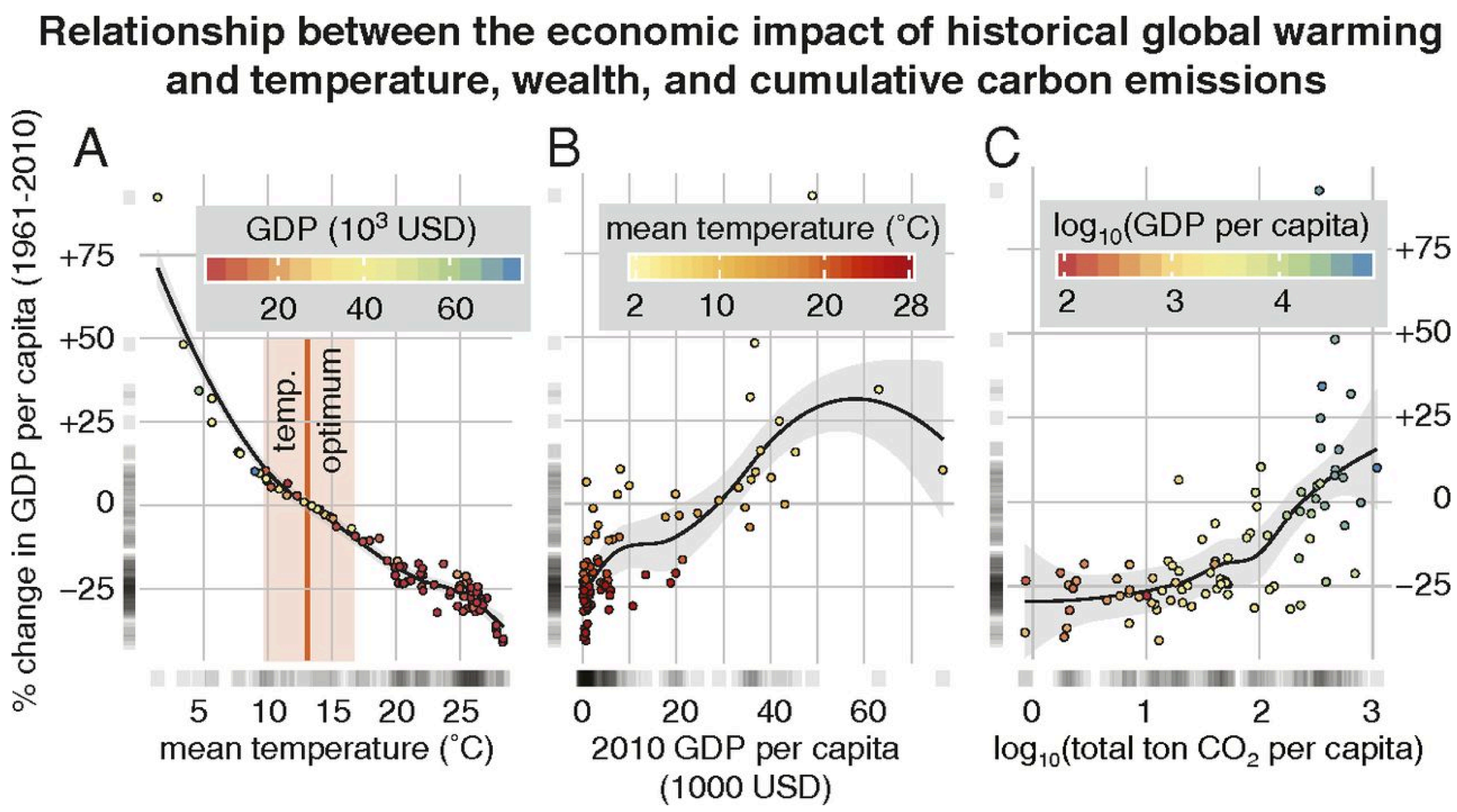

Figure 2: Graph A shows the inversely proportional relationship between % in change in GDP per capita from 1961 to 2010 and the mean temperature of that region; one can conclude that warmer regions tend to have an increase in percent change in GDP. Graph B shows the proportional relationship between % change in GDP per capita from 1961 to 2010 and GDP per capita in 2010. Countries with an increase in GDP experience a larger, positive percent change in GDP. Graph C shows the proportional relationship between % change in GDP per capita from 1961 to 2010 and total ton CO2 per capita. Countries with a positive percent change in GDP tend to emit more CO2 per capita. "Relationship between the economic impact of historical global warming and temperature, wealth, and cumulative carbon emissions." Diffenbaugh & Burke, 2019, CC BY-NC-ND 4.0.

Climate change may affect GDP, but there are other impacts that are not as well studied, such as increased pressure on poorer women. A 2014 article looked at the connection between climate change and West African migration patterns and found that climate change was indirectly impacting the quality of life for women in these areas. Since women in rural Africa already walk miles to collect water, dryer climates caused by climate change require them to have to travel longer distances to find wells and springs. This puts them not only in danger of overheating, but in danger of physical violence as they walk for hours alone (Abebe, 2014). Additionally, when tribes choose to migrate to cooler, wetter regions near mountains, women face a difficult choice. Those who choose to stay in their old homes

must learn to fill traditional male roles, but those who choose to leave often lack the resources to join the formal sector. This once again puts them at risk for physical and sexual abuse (Abebe, 2014). On a more local scale, there is evidence that changing weather patterns impact poorer communities significantly. Low-income households often live in areas more susceptible to storm damage and, because of their financial situations, many are unable to relocate. Hurricanes devastate these areas, with each significant storm raising local poverty rates by over one percent (Krause & Reeves, 2017). Because the effects of climate change are so widespread, and because the definition of inequality is so dynamic, it is difficult to predict what exactly the future could hold in terms of impact. However, we can continue to look at how these impacts occur.

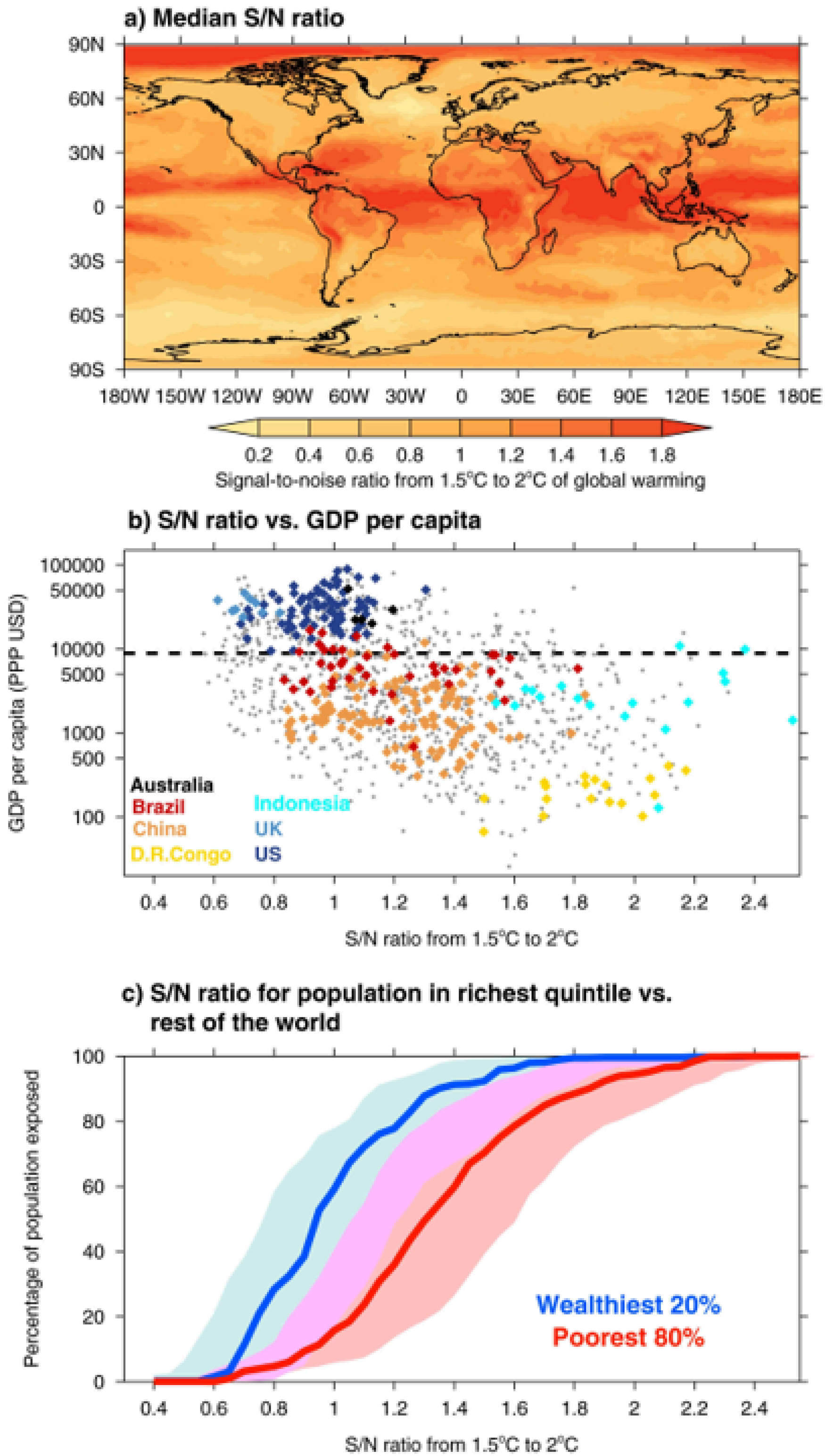
a) Median S/N ratio
90N
60N
30N
0
30S
60S
90S
180W 150W 120W 90W 60W 30W 0 30E 60E 90E 120E 150E 180E
0.2 0.4 0.6 0.8 1 1.2 1.4 1.6 1.8
Signal-to-noise ratio from 1.5°C to 2°C of global warming
b) S/N ratio vs. GDP per capita
GDP per capita (PPP USD)
100000
50000
10000
5000
1000
500
100
Australia
Brazil
China
D.R.Congo
Indonesia
UK
US
0.4 0.6 0.8 1 1.2 1.4 1.6 1.8 2 2.2 2.4
S/N ratio from 1.5°C to 2°C
c) S/N ratio for population in richest quintile vs. rest of the world
Percentage of population exposed
100
80
60
40
20
0
Wealthiest 20%
Poorest 80%
0.4 0.6 0.8 1 1.2 1.4 1.6 1.8 2 2.2 2.4
S/N ratio from 1.5°C to 2°C

Figure 3: The top map represents the median S/N ratio for various regions around the globe. This value is largest near the tropics, where many countries labeled as "poor" are. The center plot represents the S/N Ratio vs. GDP per capita, showing a slight downward trend, showing that countries with lower GDP tend to have a higher S/N Ratio. The bottom graph represents the S/N Ratio for the population in richest quintile vs the rest of the world, and it shows that the wealthiest 20% tend to have a lower S/N Ratio than the poorest 80%. "Figure 1", King & Harrington, (2018). Courtesy of AGU (American Geophysical Union).

The biosphere is the main climate system that is suffering from results of inequality, since the biosphere is the climate system in which inequality originates. The biosphere focuses on organisms that have niches in various climate systems, such as the hydrosphere, atmosphere, and lithosphere. An increase in human inequality has direct effects on the decrease in biodiversity around Earth through habitat destruction and highly localized human pressures, due to the vulnerability of biodiversity (Hamann et al., 2018). In fact, positive feedback loops between climate change, land-use planning, ocean acidification, and the nitrogen cycle have caused biodiversity loss to reach a rate 1,000 times greater than any point in recorded history. Because of this, nearly one million species face extinction (Pimm et al., 2014). Countries with heavier greenhouse gas emissions, such as Great Britain or the United States, use inequalities in industrialization and emissions as justification for their large contribution toward harming the atmosphere.

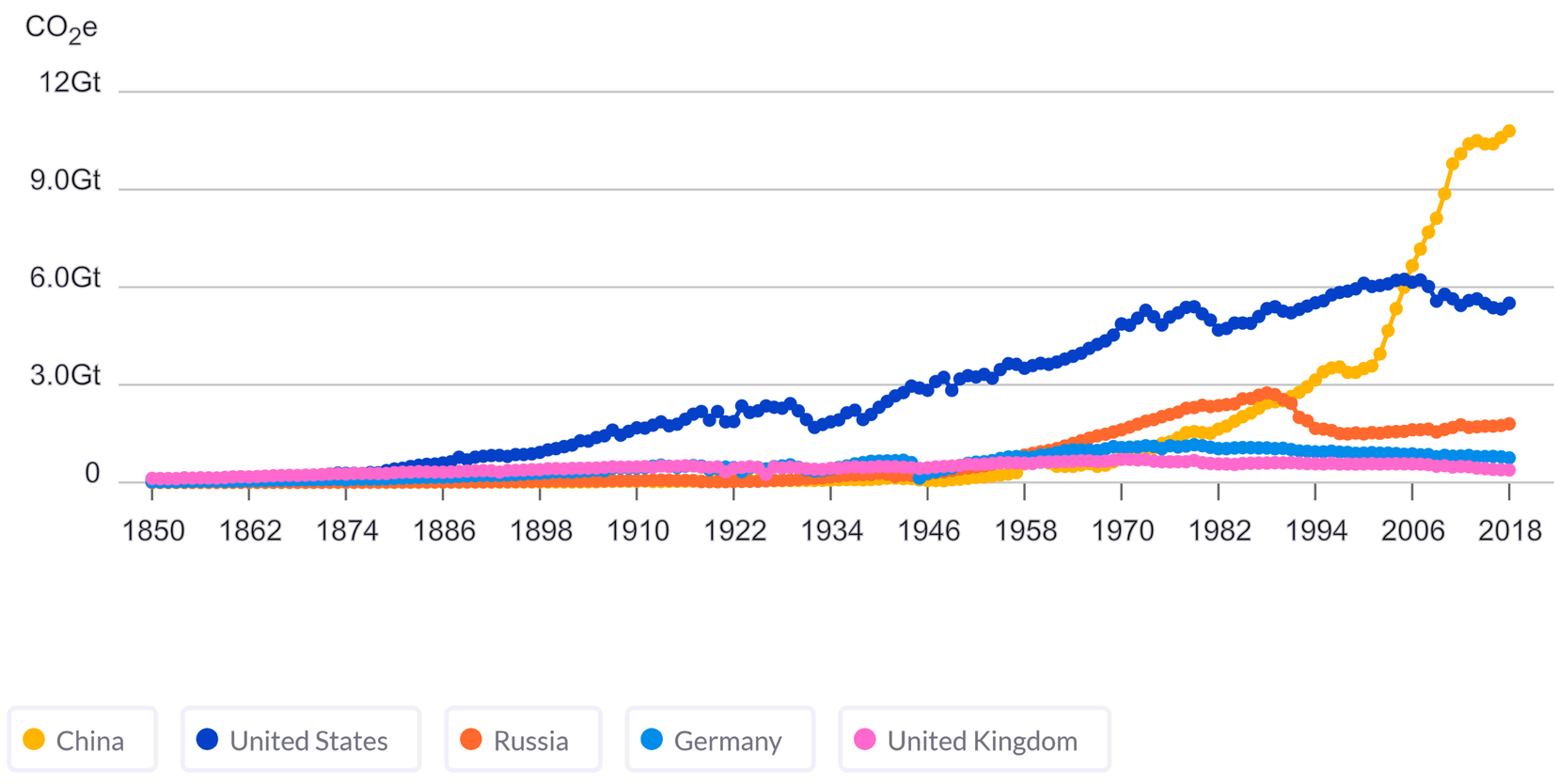

Figure 4: Graph showing the historic carbon dioxide emissions by country from 1850 to 2018. This figure illustrates which countries are most responsible for today's atmospheric content of fossil fuel gases, which greatly include the United States and China. "The PRIMAP-hist national historical emissions time series (1850-2018)", Gutschow et al., (2021), CC BY-NC International 4.0

A glance into the past is necessary for understanding emissions fully, since emitted fossil fuels take roughly a century to start showing drastic results. During the industrial revolution, wealthy business owners started using steam engines to power mills, boats, and most importantly, trains. These actions released greenhouse gases into the atmosphere, trapping sunlight within the atmosphere, and allowing Earth to warm over time as the gases stay trapped for centuries. As one can observe in Figure 4, the main countries contributing are labeled as "powerhouse countries", where the wealthiest 20% of the world live. Many of these countries are also in non-tropical regions, where atmospheric changes such as increased signal-to-noise ratios are felt to a lesser extent, highlighting a gap in regional inequality due to atmospheric shifts.

Despite these historical changes and destruction of the biosphere, there are measures being developed to fix historical mistakes.

Just as efforts are being taken to reduce the severity of warming effects and reverse climate change, strides have recently been taken to try mitigating the inequalities created. The predominant effort is the Paris Agreement, a written agreement stating that all countries signed on pledge to reduce their greenhouse gas emissions, take responsibility for contributions, and for "recognizing the specific needs and special circumstances of developing country Parties, especially those that are particularly vulnerable to the adverse effects of climate change" (United Nations, 2015, p. 3). This Agreement was the first government convention that recognized inequalities between countries since the Rio Earth Summit in 1992. Having this idea placed within the document is a large step forward, as it brings the necessary attention to the grave situations suffering countries have been put in. The Paris Agreement also covers a reduced goal temperature that seeks to keep warming under 2°C by aiming for 1.5°C instead, as it would "significantly reduce the risks and impacts of climate change" (United Nations, 2015), thus lessening the burden on all affected states. One issue with the Agreement though is a lack of binding requirement for each country to reduce their emissions and rather a general call to action for the signees to try their best, which may backfire. While there are a couple of viable, large scale efforts being made to save the planet, there are also a multitude of smaller regions that are striving to save themselves.

Changes on a local level are important for making large impacts, and resilient cities are a significant adaptation. Resilient cities are cities that are taking measures to ensure protection from economic, societal, and environmental damage caused by climate shifts. Cities are constantly updating how they regulate industry and foster economic success while maintaining human-made and natural assets. In addition, each upholds a standard for the basic needs of their community members. This is done by "enable[ing] individuals, communities, institutions and businesses to participate in the

definition and execution of policies" (Gemeren, 2017), ensuring that safe policies can be put in place regarding climate change. Not only does this protect local communities, it sets precedent for how larger-scale organizations (like governments) should approach the human issues surrounding climate change. Policies similar to those in resilient cities can ensure a reduction in contribution to climate change and promote climate equality over regions and cities, relieving the disadvantaged of their climate-based burdens and inequalities. On a larger scale, resilient cities set standards on what green living can look like. They prove the possibility of a cleaner world with just as much prosperity as a carbon-intensive one. As the world comes together to end climate change, humans must question if there a scenario in which the inequalities formed in its wake are able to be torn down with it.

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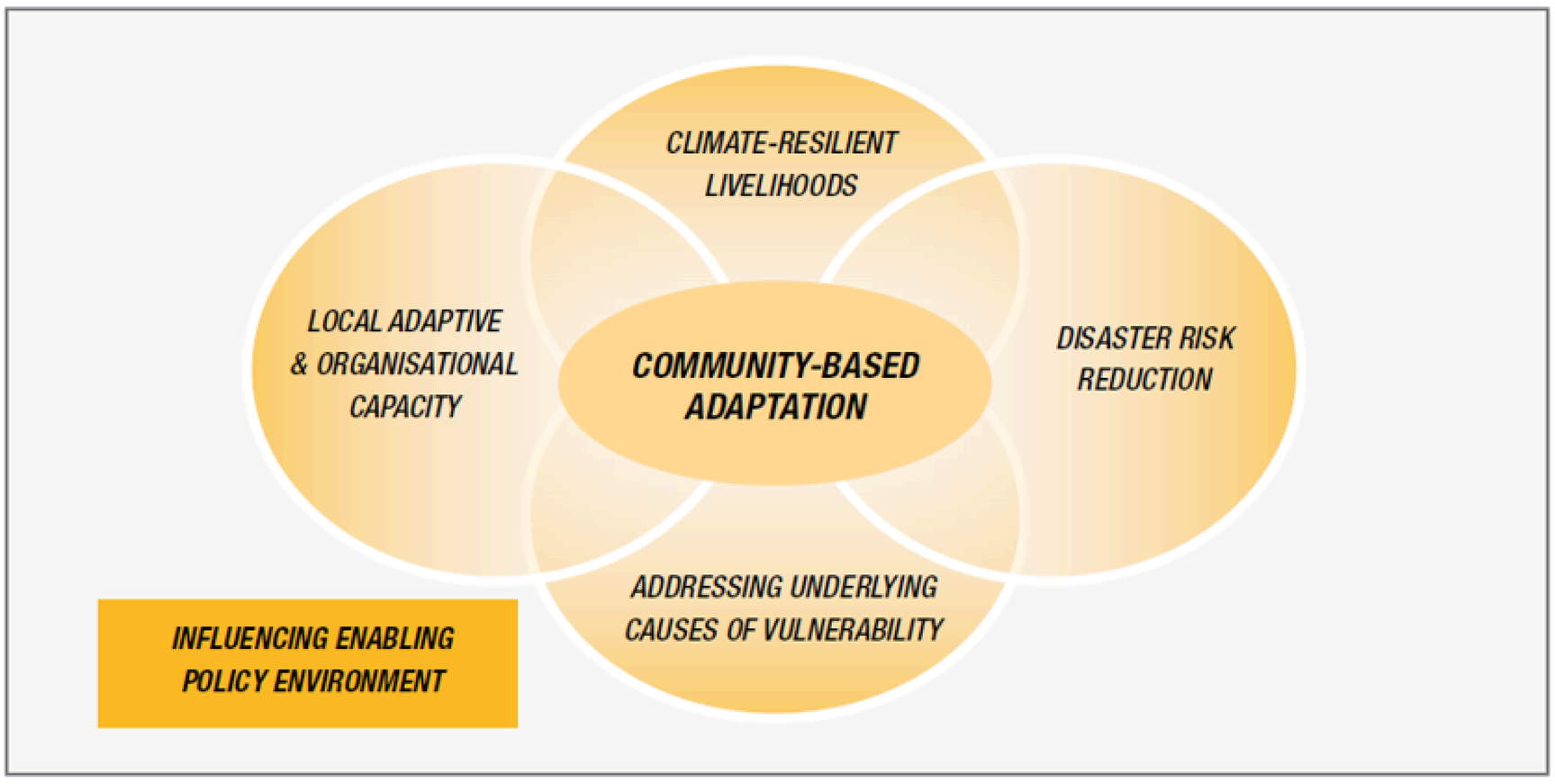
PART III

COMMUNITIES AND CLIMATE CHANGE

In the following set of chapters, students studied community-based adaptation and mitigation strategies in response to a changing climate (see Figure below). In particular, they researched a specific community to begin to get a sense for its overall social, economic, technological, and environmental conditions. Furthermore, they mapped the community's assets and vulnerabilities in relation to the community's climate challenges, opportunities, and resilience. Broad areas of background they could investigate for each community included: population density, education levels, major industries, economic health, overall climate, political structures, and technological access and capabilities and how these factors relate to climate change in that location.

Students explore climate change for residents and ecosystems in Puerto Rico in Chapter 9, with an emphasis on shifting agricultural and industrial practices. In Chapter 10, students seek to understand the current threats to Boston, Massachusetts, especially given historical decisions to create land from the sea. Next, Chapter 11 focuses on the consequences of changes in rainfall and temperature to agricultural properties in the Himalayan Mountains. The island nation of Fiji, is facing a multitude of threats (e.g., sea level rise, changes in precipitation) from climate change, and students explore these topics in Chapter 12.



Community-based Adaptation (CBA) framework designed by CARE (Cooperative for Assistance and Relief Everywhere). "Figure 1. The original 2009 CARE CBA 'flower' diagram" from King, S. (2014). Community-Based Adaptation in Practice: A global overview of CARE International's practice of Community-Based Adaptation (CBA) to climate change. Used with Permission.

9. Puerto Rico

By Keelan Boyle, Katherine Corbin, and Daniel Shea

Abstract: Puerto Rico's land, economy and values have changed significantly over the years. Agriculture was traditionally the main source of income for Puerto Rican residents, but during the onset of the industrial revolution, land became limited, resulting in a non-successful economy and a poverty-stricken territory. Climate change does not just affect the land, but also the plants, animals, and humans living in Puerto Rico. The impacts of climate change have been seen in Puerto Rico as hurricanes have become more common. This has also caused drinking water to become contaminated. Environmental impacts have been seen and possible solutions for contaminated water are being pursued. Will Puerto Rico be able to adapt to these new challenges caused by climate change?

Introduction to Puerto Rico

Puerto Rico is an island territory of the US in the Caribbean with a vast history and culture. With a population of 3.2 million, Puerto Rico has gone through dramatic changes in the hundreds of years that Westerners have been aware of it (CIA, 2018). Over the years, the prevalent economic driver has shifted from agriculture and a slave-based labor system to today's growing industrial sector (Fain

et al., 2018). With this shift, as well as the increasing effects of climate change and hurricanes, the climate has become an increasing worry for the citizens of the magnificent island. Solutions have since been found to try to combat these problems.

The History and Culture of Puerto Rico

Puerto Rico has been inhabited for over 4000 years (since 2000 BCE) by people who first settled in the vast mangrove ecosystems (Rob, 2016). Around two thousand years later the Saladoid people came to Puerto Rico from modern day Venezuela and brought more advanced agriculture and pottery techniques to the island and replaced the existing Ortoiroid culture (Rob, 2016). As this civilization continued to thrive it expanded across the Caribbean. This new Saladoid society had a focus on politics and art. After Christopher Columbus made his journey to the Americas, the Spanish started to take control of the island (1508 CE) (Pierce, 2010). In 1523 the first sugar cane processing plant was established, starting one of the main industries of the island along with coffee, which was introduced to Puerto Rico during the 18th century. After the Spanish-American War (1898) the USA incorporated Puerto Rico as a territory (Pierce, 2010). On August 12, 1898, President William McKinley and French Ambassador Jules Cambon signed an armistice in Washington DC, stripping Spain of its control over Puerto Rico, as well as Cuba and the Philippines, and giving control of these countries to the United States (Rivera, 2020). Puerto Rico was officially ceded to the United States on September 29th, 1898 (Rivera, 2020). The reason the United States decided to take control of Puerto Rico was to implement a strong sugar market here (Little, 2017). Ironically, this industrialization has led to decreasing agricultural suitability.

Another major industry in Puerto Rico that had a significant presence on the island was coffee production. Climate change has

created disadvantages to agricultural sales around the world, one of these being coffee production (Fain et al., 2018). Coffee production was at its peak in the late 19th century, but when the United States took the country over in 1898 as a result of the Spanish-American war, it was easily able to industrialize Puerto Rico. This made agriculture scarcer (Fain et al., 2018) and led to current harvesting reaching record lows. The reduction of rainfall around Puerto Rico due to climate change has also negatively impacted its remaining agricultural farms. Projections show that Puerto Rico could hold only 24 square kilometers of suitable land for agriculture by 2071, which takes up less than 0.3% of the island (Fain et al., 2018). As one can see in figure 1 under even the best conditions, coffee suitability is projected to exponentially decrease in the next 20 years despite the availability of land.

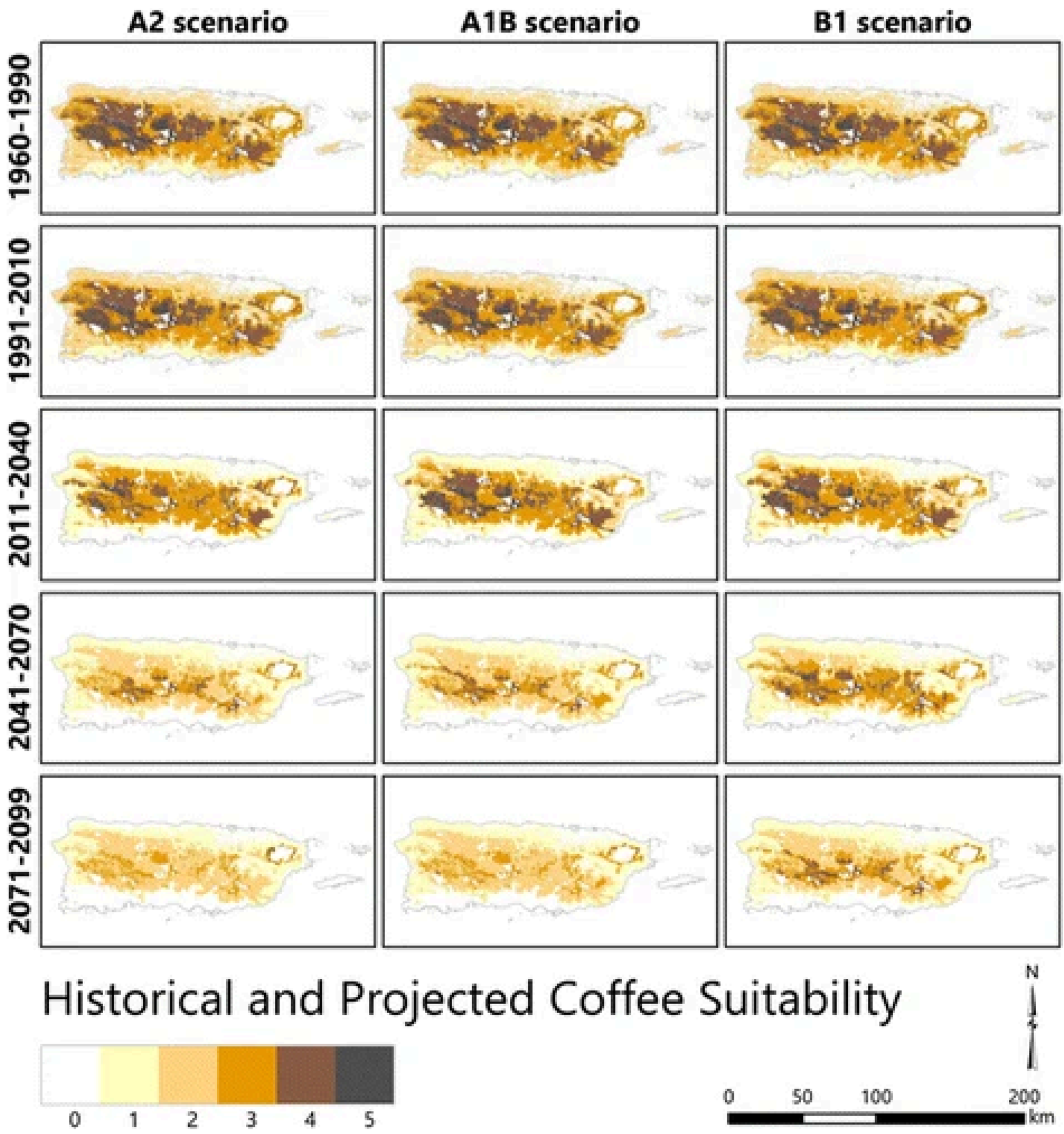


Figure 1. Coffee suitability from 1960 to 2099 with A2 being the worst-case scenario, A1B being the expected scenario, and B1 being the best-case scenario. "Historical and Projected Coffee Suitability", Fain et al., (2018). Courtesy of Climatic Change.

Puerto Rico was not always known for its industrial cities and unsuitable agriculture. In 1815, the country developed a strong agricultural economy, where the main investments included cattle, sugar cane, tobacco, and coffee (Rivera, 2020). However, by 1867, which was the onset of the industrial revolution, agriculture was limited by lack of roads, low quality tools, and natural disasters, such as hurricanes and droughts. This brought about a sharp increase of

poverty-stricken citizens since agriculture was the main source of Puerto Rico's income (Rivera, 2020).

Despite poor agriculture and decreasing coffee suitability, Puerto Rican residents are resilient when it comes to climate change. The Greater Antilles region has been subject to historic periods of high precipitation and low sea levels. Puerto Rican residents have responded to change in precipitation in various ways; one example being the people of Angostura, who reside in northern Puerto Rico, who relied heavily on their location. Because of this, they implemented technology to adapt to this change (Rivera-Collazo et al., 2015). Residents of the Maruca group in southern Puerto Rico, however, were not as reliant on their location, so they would evacuate until more ideal conditions came about (Rivera-Collazo et al., 2015). Both locations are directly on the coast. The locations of these groups and the resources they had show how Puerto Rico has adapted due to climate change. All in all, Puerto Rico is a land with rich history and various cultures spanning back 1,000 years before the arrival of the Spanish (Britannica, 1999). These various cultures have led to Puerto Ricans responding to seasonal climate change in numerous ways, depending on their values and priorities.

Figure 2. A Map of Puerto Rico. USGS, Public Domain.

Major Industries and Economic Health

The major industries in Puerto Rico have been greatly impacted by climate change. Since Puerto Rico has poor agriculture, the industrial sector plays a more significant role in the economy. Tourism, one of Puerto Rico's major industries, also significantly impacts the economy. Very low job opportunities in Puerto Rico has caused a rise in outmigration to the mainland of the United States, with the unemployment rate of Puerto Rico hitting 16% in 2011 (CIA, 2018). This number eventually declined to 11.5% in December 2017 (CIA, 2018). The minimum wage laws that are present in the US apply to Puerto Rico which has halted job expansion and the income per capita to about two-thirds of the mainland of the US (CIA 2018). The economy in Puerto Rico has also been greatly impacted by the effects of climate change. Persistent and strong hurricanes have greatly damaged electricity in Puerto Rico impacting manufacturing and the economy. Even though Puerto Rico is a US territory, it rarely receives aid from the mainland after these natural disasters. This has also negatively hurt Puerto Rico and its economy.

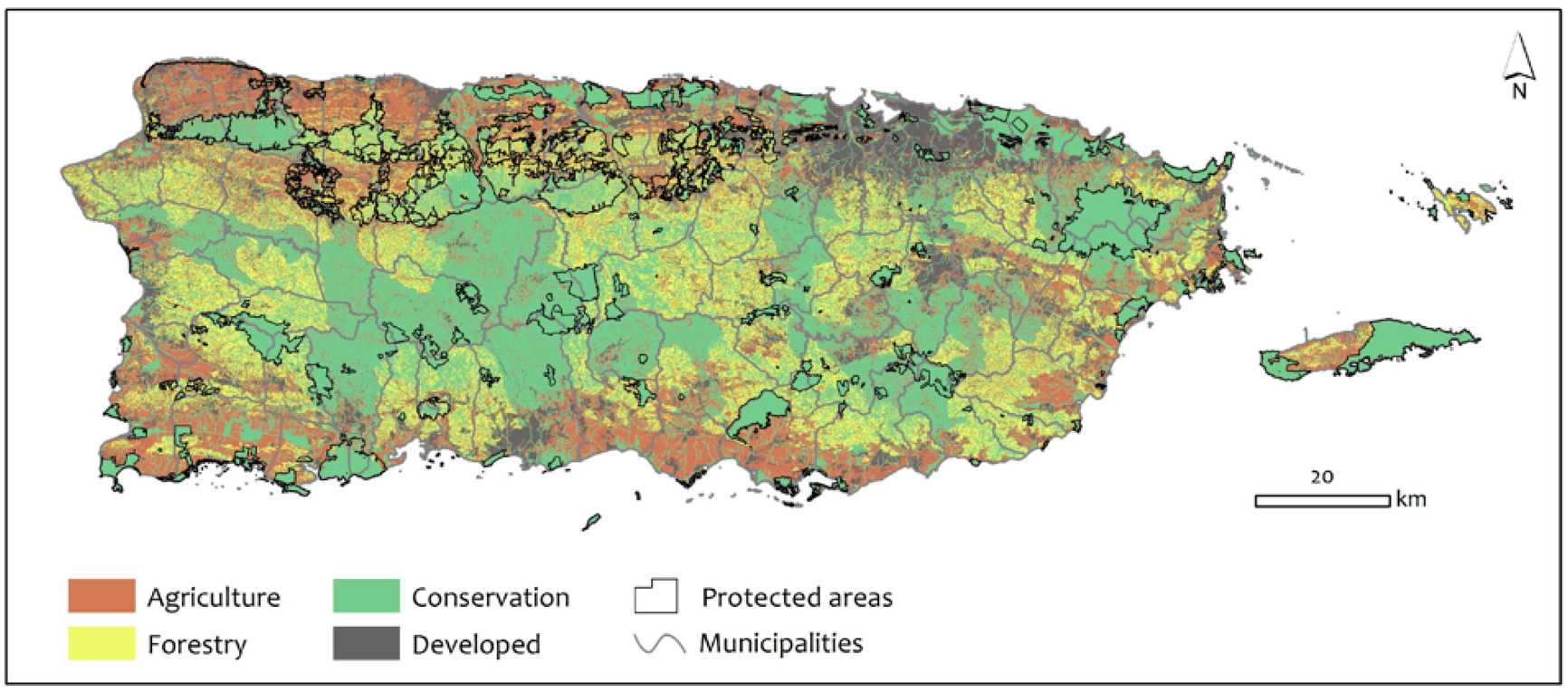


Figure 3. Land use in Puerto Rico in"Figure 7", Gould et al., (2017), CC BY 4.0 International

Land Use, Resources, and Ecology

Tourists come to Puerto Rico from all over for a tropical paradise with sandy beaches, a tropical climate, and the multitudes of forests that cover the Cordillera Central, the main mountain range on the island with an elevation of 3000 feet [see the middle map of figure 2] (Britannica, 1998). Coming down from the mountains are a multitude of different rivers that supply animals and people with water. The La Plata River and the Río Grande de Loíza are two of the island's longest and most important rivers (Britannica, 1998). Both provide unique services to the island; the La Plata River provides hydroelectricity and the Río Grande de Loíza provides water for a vast number of agricultural needs (Britannica, 1998). Both rivers also support forests that cover approximately 63% of the 8,959 square kilometers of Puerto Rico (CIA, 2018). As explained earlier, the amount of land used for agriculture has been significantly reduced over the last few decades. This has allowed the forest to take back much of the island with the help of humans from the 1950s to now (Brandeis et al., 2009). With humans introducing new species and changing the environment, the variety of species of trees is at an all-time high and no local trees have gone extinct. Within the forests and other environments there are over 9,000 different species of animals in Puerto Rico. This includes many endangered species whose homes are being destroyed due to habitat loss. One of the more notable endangered species is the Puerto Rican Parrot (see Figure 4), whose habitat for these parrots is in forests with suitable notches for nesting and fruit for food. There are fewer than 200 of these birds left on the island and only 30 left in the wild (Endangered Species Coalition).

Figure 4. "Puerto Rican Parrot / Cotorra Puertorriqueña" by Pablo Torres, USFWS, Public Domain.

With the introduction of more and more humans to the island, the forests have gone though many different changes. This includes the near-total annihilation of old growth forests and the carving up of land for agriculture; at one point up to 68% of the island was cleared for agriculture, even though agricultural land only occupies 13.4% of the island currently. The other major use of land is for industry (CIA, 2018). As the modernization of Puerto Rico and its economy continues, the amount of land used for industry will also increase from the current 14.8% (CIA, 2018). This will cut into the forests and tax the natural resources on or near the island. A driver for this is the vast amounts of oil and natural gas that are off the island's coast. With the shift towards renewable energy sources, however, these resources may not be used for a long time. If Puerto Rico were to pursue renewable energy, the main sources would most likely be solar, wind and hydroelectric.

Effects of Climate Change and Environmental Issues

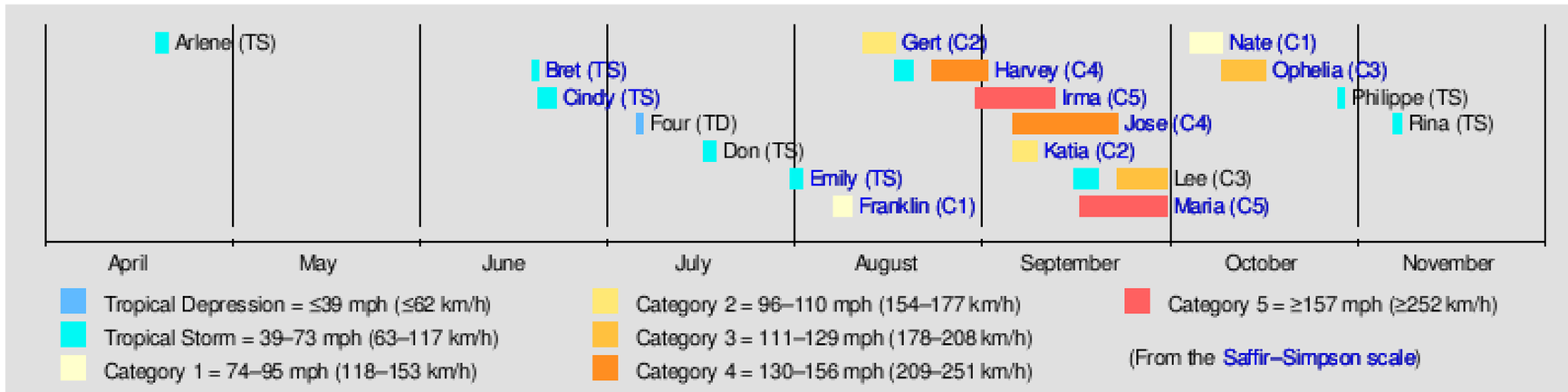


Figure 5. This shows the different storms and their severity that hit Puerto Rico in 2017. "Timeline of the 2017 Atlantic hurricane season" CC BY-SA 3.0

Puerto Rico has experienced its fair share of environmental and social problems due to climate change. There are significant social issues present in Puerto Rico including class divide and an uncertain political status (Comas-Diaz et al., 1998). On top of this, Puerto Rico has experienced the impacts of increasing natural disasters due to climate change as seen in Figure 5. In September of 2017, Hurricane Maria hit Puerto Rico causing electrical power outages that impact 90% of the territory. There was significant damage to infrastructure and housing with the contamination of drinking water (see Figure 6; CIA, 2018). Often when Puerto Rico experiences natural disasters like Hurricane Maria, the US will not help repair the damage. Despite and because these significant environmental issues that are present in Puerto Rico, efforts have been made in the territory to look at the use of solar energy for small rural water systems. The high cost of electricity in Puerto Rico has greatly impacted the treatment and distribution of clean drinking water. In 2019, the EPA conducted a research project in which they looked at the efficacy and the possible use of solar-powered water delivery systems in Puerto Rico (Patterson et al., 2019). The rural water system that was present was damaged by Hurricane Maria, but solar panels were not damaged (Patterson et al., 2019). Solar energy could

be beneficial in Puerto Rico and could help with the damage caused by Hurricane Maria and other natural disasters. Other measures have also been taken in Puerto Rico to protect the environment and to act against climate change. In 2007, the "Puerto Rico Declaration on Climate Change" was signed in order to evaluate the impacts of climate change and assess possible adaptation and alternatives to global changes in Puerto Rico (PRCCC, 2013). Groups like the "Puerto Rico Climate Change Council" have made great change regarding environment issues and slowing down climate change in Puerto Rico. Puerto Rico has experienced the impacts of climate change and has also made actions to lessen its affects.

Figure 6. The photograph displays the damage caused by Hurricane Maria. Civil Air Patrol in cooperation with the Air National Guard does an aerial survey over northern Puerto Rico Sept. 26, 2017 after hurricane Maria impacted the island on Sept. 20, 2017. "Hurricane Damage Assessment", U.S. Air Force photo by Airman 1st Class Nicholas Dutton, Public Domain.

Conclusion

As a small, poor island territory Puerto Rico and its many people and communities are particularly vulnerable to various natural disasters and changes in the environment. Industrialization of the economy

has caused environmental issues have started to hurt the vast amount of biodiversity and different population centers. But with this, there are organizations that are looking to combat the effects of climate change on Puerto Rico.

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10. Boston

By Elizabeth Dahlberg, Gabriel Espinosa, and Jack Hanlon

Abstract: Boston, Massachusetts is a particularly diverse city within the United States and has a wide range of assets that place it at the forefront of climate change innovation. However, historical decisions made by the city have begun to present issues with weather pattern shifts and rising sea levels. There are cultural aspects of the city though, particularly education, that show promise in containing and diminishing the effects of climate change within the region. Boston has a strong and wealthy post-industrial economy built around healthcare, business, and education, maintaining a plethora of jobs in modern industries. Although the city often attempts to curtail economic inequalities the extensive poverty rate in the region is impossible to ignore. The greater New England area has been working over the past two decades to diversify renewable energy resources and lessen dependencies on imported goods, better preparing its people for a future of changing climate impacts. Boston's land is mostly man-made land. The land was originally used for mills, but was covered up by sand, trash, and earth from Beacon Hill. Boston's harbor is home to many diverse plants and animals, some are protected by the government and are endangered species. The harbor helps Boston with flood control and water filtration and mixes the freshwater

rivers and the saltwater Massachusetts Bay creating an estuary in Boston Harbor. How will the metropolis fair in our rapidly changing climate future?

Boston's Assets and Vulnerabilities to Climate Change

Boston has an exceptionally rich history, with notable events such as the Boston Massacre and the Tea Party occurring directly in the city, but one large scale project that begin in 1856 in response to a population boom is often overlooked. The filling in of the Back Bay is one of the most vital pieces of Boston's history, and brought unmatched expansion in population, economic assets, and land to a city struggling with overpopulation at the time. However, this change (Figures 1 & 5) is now bringing up a variety of issues for the region, as much of the land was built at sea level, which, "similar to other coastal cities that were developed or expanded by filling wetlands, ... is low lying and susceptible to flooding" (Bowen et al., 2019). A city commissioned report has also stated that predictive models of business-as-usual climate change may lead to a sea level rise of nearly 3 feet by 2070, flooding vulnerable spots, which stated by

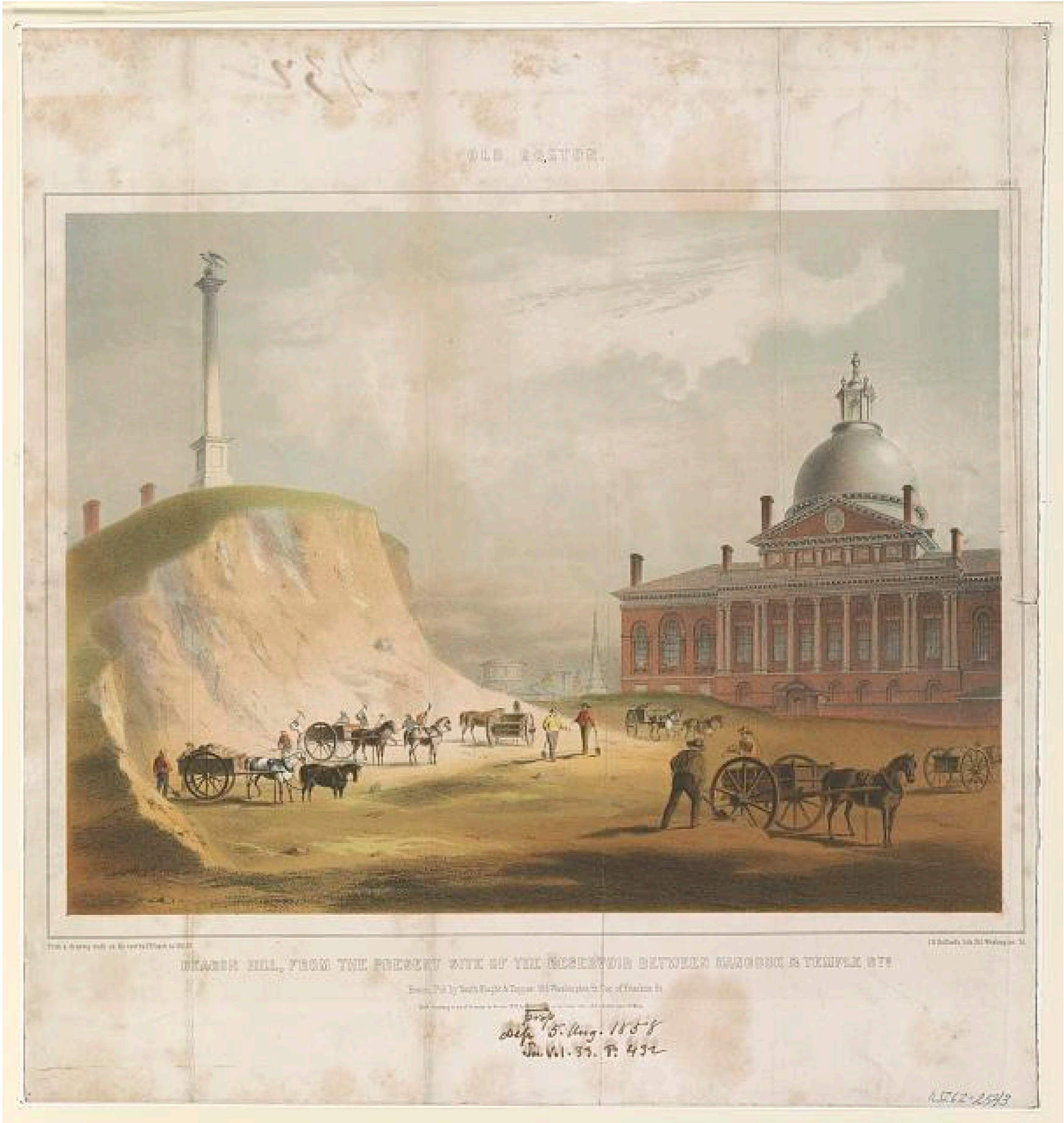

Figure 1. This image shows workers removing Beacon Hill, one of the 3 main hills of colonial Boston used to fill in the Back Bay and help form the shape of current day Boston. "Old Boston. Beacon Hill from the present site of the reservoir between Hancock & Temple Sts." from a drawing made on the spot by J.R. Smith in 1811. Library of Congress Prints and Photographs Division Washington, D.C. 20540 USA, Public Domain

the report "are commercial piers, Logan International Airport, low-income neighborhoods, the South End, and the New England Aquarium" (Mufson, 2020). Studies done by other universities, such as Harvard and Boston University, have also pushed officials to make changes, such as Mayor Martin J. Walsh, who "has vowed to spend more than $30 million a year … to defend the city from a watery

future that is expected because of climate change" (Mufson, 2020) under the cities new budget plans for the next 5 years.

Boston, Massachusetts is an extremely culturally diverse city within the United States and has been that way since it was established in 1630. This is primarily due to a large majority of early settlers being immigrants, which have accounted for up to 36% of Boston's total population since 1850 (Figure 2), and much of this drive is attributed to education, one of the cities greatest assets (See Appendix 1, at end of chapter for a map of the city's assets and vulnerabilities to climate change). While there are a plethora of different arts, social institutions, ethnicities, and religions, the 54 higher educational institutions found within the area highlight the regions dedication to and culture of learning. The intense level of care for learning has led Boston to become a forefront in a multitude of different societal advancements, with one such advancement being its acknowledgment and preparedness for climate change and natural disasters. A George Washington University study found that academic sources are one of the most important factors in motivating cities to adapt to climate change, and that "work done by Massachusetts Institute of Technology and the Union of Concerned Scientists played important catalyzing roles in helping local officials understand what might happen in their city" (Carlson et al., 2015).

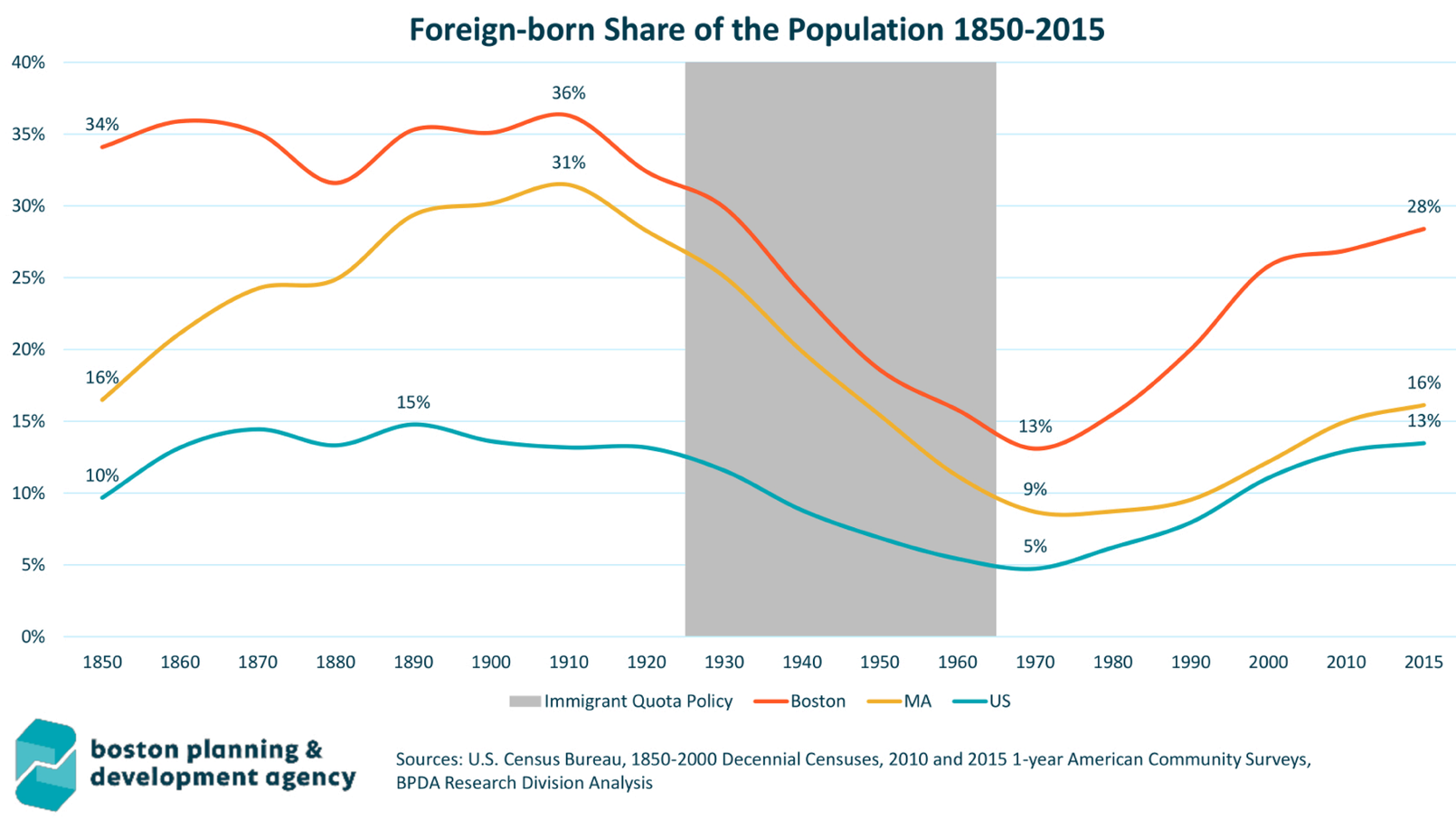

Figure 2. Pictured above is a graph that shows the percentage of the total population that is foreign-born in Boston, Massachusetts, and the United States. It highlights the diversity in the population. "Foreign-born Share of the Population 1850-2015", Boston Planning & Development Agency, CC BY 3.0

Boston is an economically and socially developed city of more than 700,000 people as of 2019. The city is home to diverse ethnic groups with over 48% of the population identifying as non-white and 28.5% identifying as foreign born (U.S. Census Bureau, 2019). Boston maintains a post-industrial economy with 142,000 people working directly in health care, insurance, and higher education, shifting the city far from its manufacturing roots (Lima, et al., 2011). With nearly 50% of the population 25 years or older having a college degree, education acts a vital export fueling a modern economy. Although the median household income in the metropolitan area is over $65,000 per year, 20% of the city's population is characterized as below or at the poverty line, defined by making $12,000 yearly or less per person of working age in a family (U.S. Census Bureau, 2019). As seen in *Figure* 3, many lower income communities are in low elevation parts of the city and will face the effects of rising sea levels head on. It is important to note that wealthier communities in similar shoreline regions, however, have access to resources that

will leave these areas better prepared for the climate impacts (Kirshen et al., 2008).

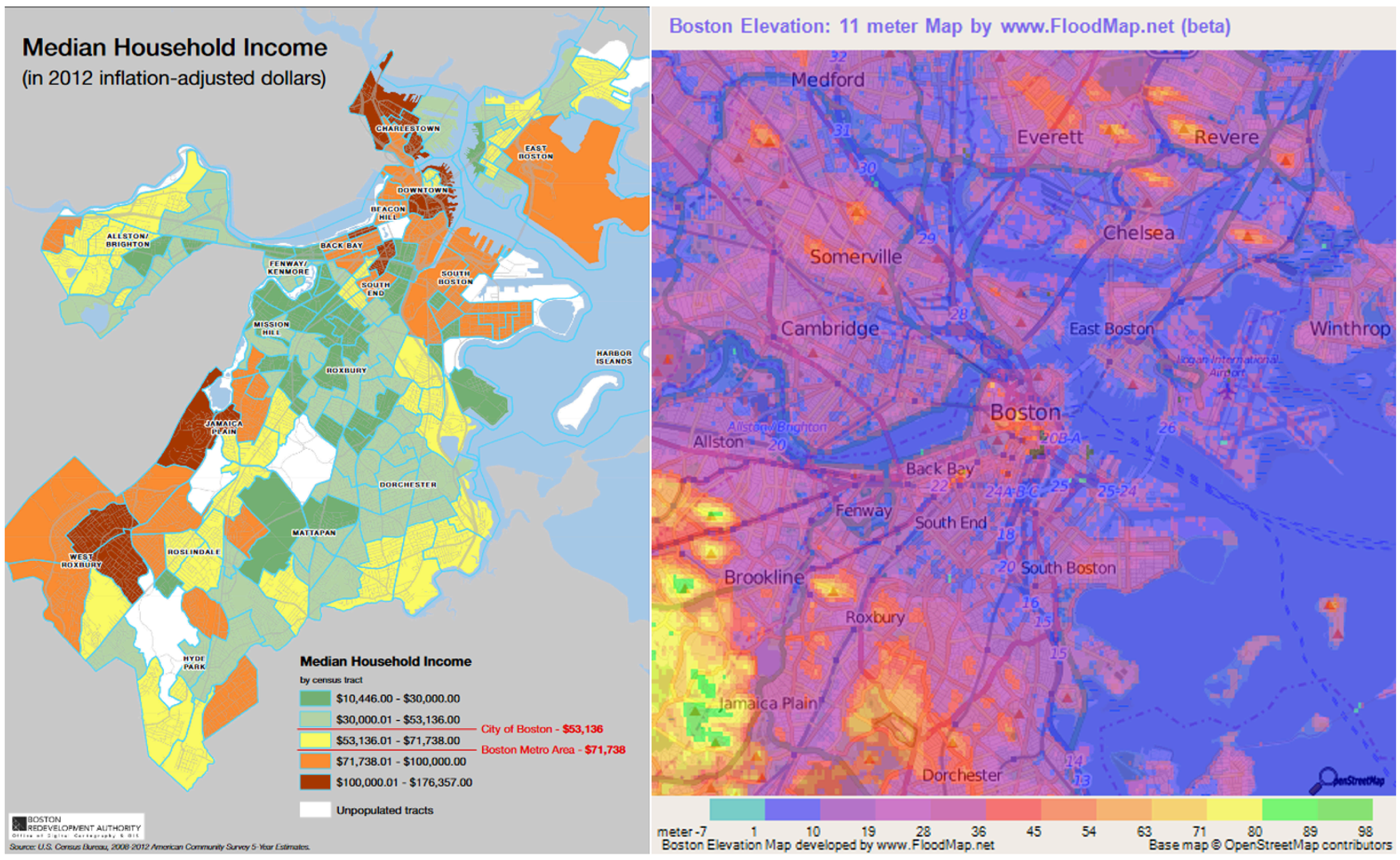

Figure 3: (Left): A map of the greater Boston area displaying wealth distribution by median household income. Green regions are defined as lower income while brown regions are defined as higher income. "Median Household Income", Boston Planning & Development Agency, CC BY 3.0. (Right): An elevation map of the city of Boston, blue is defined as sea level and increasingly red areas are higher elevation. "Boston, US Elevation Map" (2020), CC BY-SA 2.0

Boston and the greater New England is still heavily dependent on fossil fuels, making up 42% of the total energy supply, comprised of coal, oil, and natural gas (Gellerman, 2019; Figure 4). The remainder of the North East's power input comes mostly from nuclear power plants, accounting for 40% of the total energy supply in the region. While there is still much work to be done in converting to all renewable sources, New England has seen a rapid disassociation from coal and oil power generation, decreasing usage by 32% since 2000. Contrasting this progress is the increased dependence on natural gas by 27% over the same period (Gellerman, 2019).

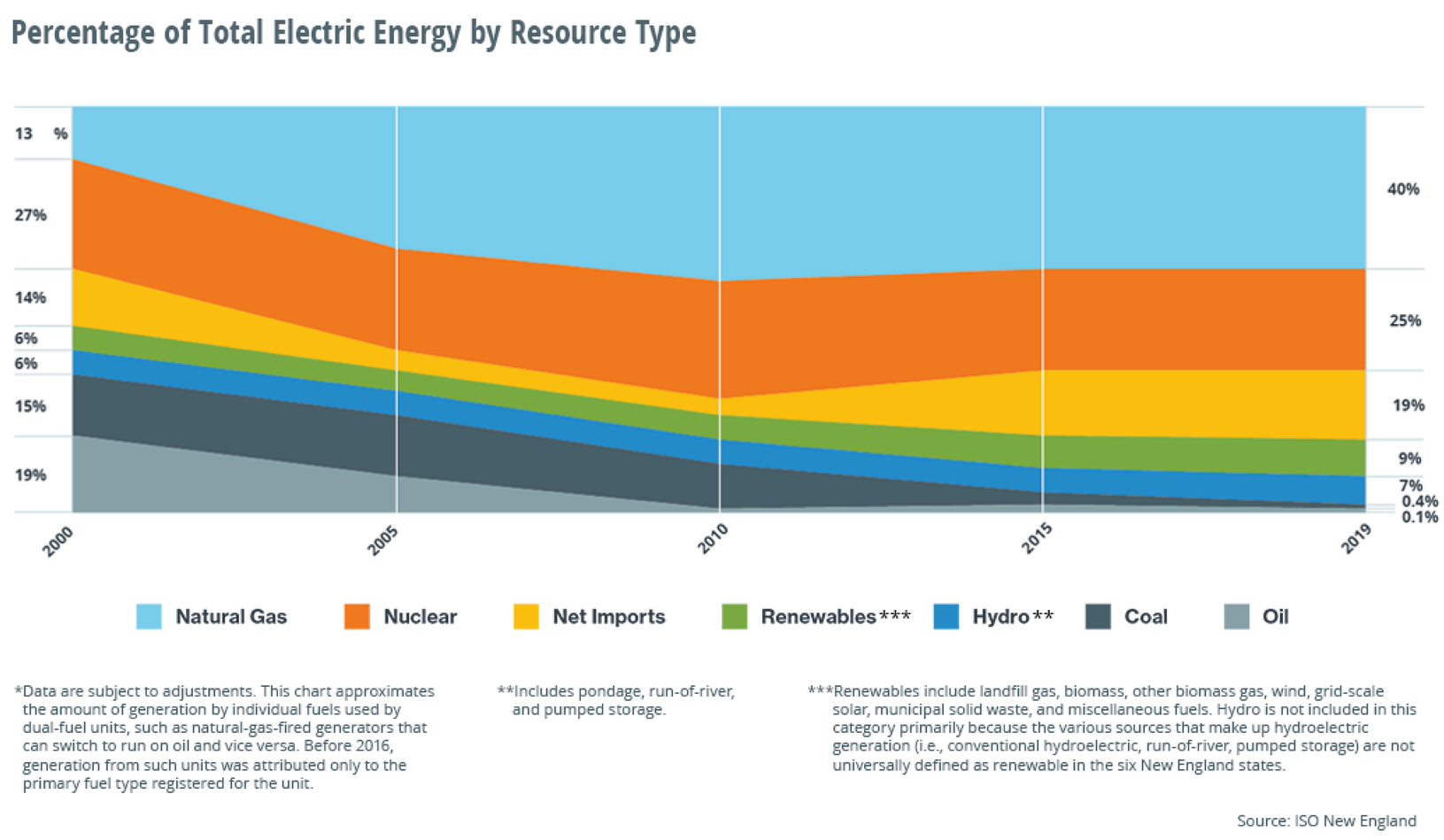

Figure 4: The above graph shows the energy makeup of New England between 2000 and 2018. A clear decrease in reliance on coal and oil energy sources in evident while the largest increase in dependency falls on natural gas. "Percentage of Total Electric Energy by Resource Type", Courtesy of ISO New England

Water recourses in Boston are almost entirely locally sourced by reservoirs, rivers, and lakes throughout Massachusetts such as the Quabbin and Wachusett reservoirs. These water sources are projected to sustain the water demand of local communities for the foreseeable future and will act as a critical safety net for the region as climate change progresses (Suarez et al., 2005). Boston uses a mix of both imported and locally sourced food to supply its growing population (Loh & Agyeman, 2019). At this point nearly all food resources, internally or externally sourced are under threat from climate change as growing cycles and regions shift further north. Although the future of food in quite bleak, Boston has begun implementing food distribution systems for lower income communities struggling with accessibility (Loh & Agyeman, 2019).

Boston was established in 1630 on Shawmut Island by Native Americans (Mason, 2017). Throughout history Boston's geographic features have changed because man-made land was used to create

the Boston that we know today (Figure 5). Many of these man-made lands were the lands that use to power mills. Boston is a town with lots of hills, most known is Beacon Hill. During Boston's expansion, the material to make new land was taken off Beacon Hill. In addition, they used trash, mud from South Bay, sand and gravel from Needham. The ecology of Boston Harbor is important to Boston because it provides help during floods. The freshwater river, the Charles River, is used for rowing competitions. The Boston Commons and the Boston Public Garden are used to exercise and places for communities to come together. Boston has grown so much throughout history and because of this it is susceptible to climate instability.

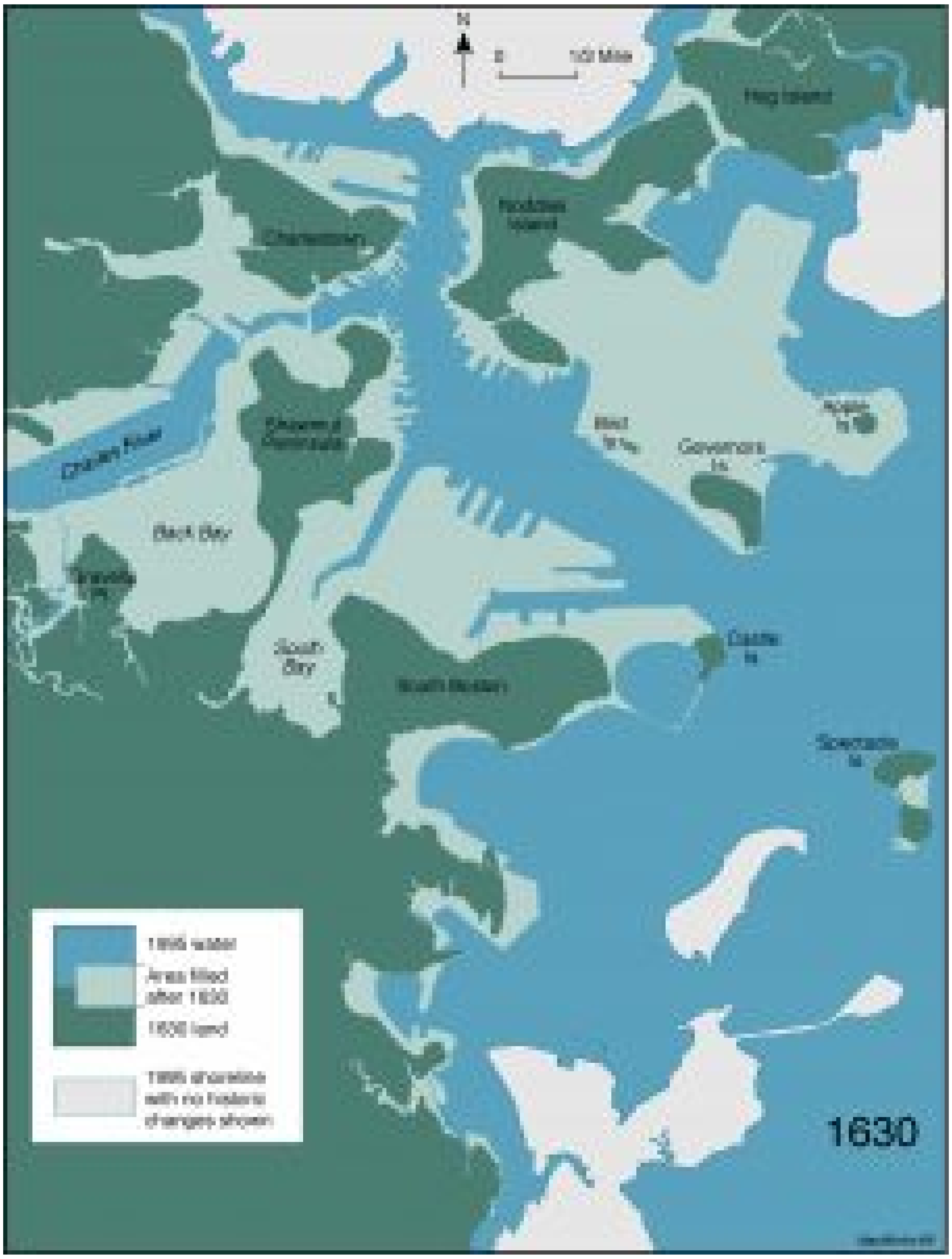

Figure 5. The Land of Boston when it was founded and the change to Boston's land. "Boston shoreline 1630", Map reproduction courtesy of the Norman B. Leventhal Map & Education Center at the Boston Public Library, Public Domain.

The Boston harbor is an estuary that connects the freshwater rivers, Charles, Mystic, and Neponset, and the saltwater Massachusetts

Bay. The estuary provides Boston with flood cover and water filtration. It also provides important habitats for wildlife and is a nursery for marine organisms (National Park Service, 2015). This estuary is home to many diverse plants and animals. It has fauna from Maine, one type of eelgrass that was once plentiful, and has salt marshes. Whales, dolphins, and seals migrate and eat near the harbor. Their wildlife is very diverse and sees around 100 different bird species (National Park Service, 2015). The flora of the estuary is not the natural flora because of human alteration and many invasive and exotic species. The ecosystem does provide a home to six rare species of birds and two protected species of plants. There are endangered and threatened species of plants and animals in the Massachusetts coast, but are not found in the estuary (National Park Service, 2015). This estuary is very important to the wildlife of the coast and Boston, because without this estuary Boston could experience more disastrous floods in the future.

The metropolis of Boston has a history rooted in diversity and a people tied closely to the low-lying land around the bay. With the onslaught of climate change looming over the horizon, the city is more prepared than most to handle the challenges ahead. With goals to be carbon neutral by 2050 and resolve impact inequalities within the region, Boston and its people have daunting forthcoming. Will they be up for the task?

Appendix 1. A map of assets and vulnerabilities to climate change for Boston, Massachusetts. Credit: chapter authors.

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11. The Himalayas

By Isabella Clowes, Nora Smith, and Alexander Wadsworth

Abstract: The Himalayas' relative isolation has led to a rich and complex culture that varies by area, and the mountains themselves hold significance in many of the major religions in Asia. The economy of the Jammu and Kashmir region is dominated mostly by agriculture and handicraft industry. The agriculture industry specifically is susceptible to climatic changes because the recent decrease in rainfall and increase in temperature creates worse conditions for traditional farming and great ones for smaller scale horticulture. Additionally, the mountains are home to many river basins and glaciers which provide fresh water for several different populations. Recently, these water stores have been threatened by climate change. Hopefully the people of this region will be able to adapt to the effects of climate change through smarter water management, advanced planning for disasters, and environmental protection programs. Ideally, this region will have to reduce their contributions to climate change in order to preserve their way of life.

The Himalayas

While many parts of Asia hold global significance, the Himalayas are a more localized region with great importance. They span roughly 1,500 miles, passing through 6 countries including Pakistan, China, and India (Figure 1). The area focused on in this paper is the Jammu and Kashmir region of India, which is located in the north of the country of India.

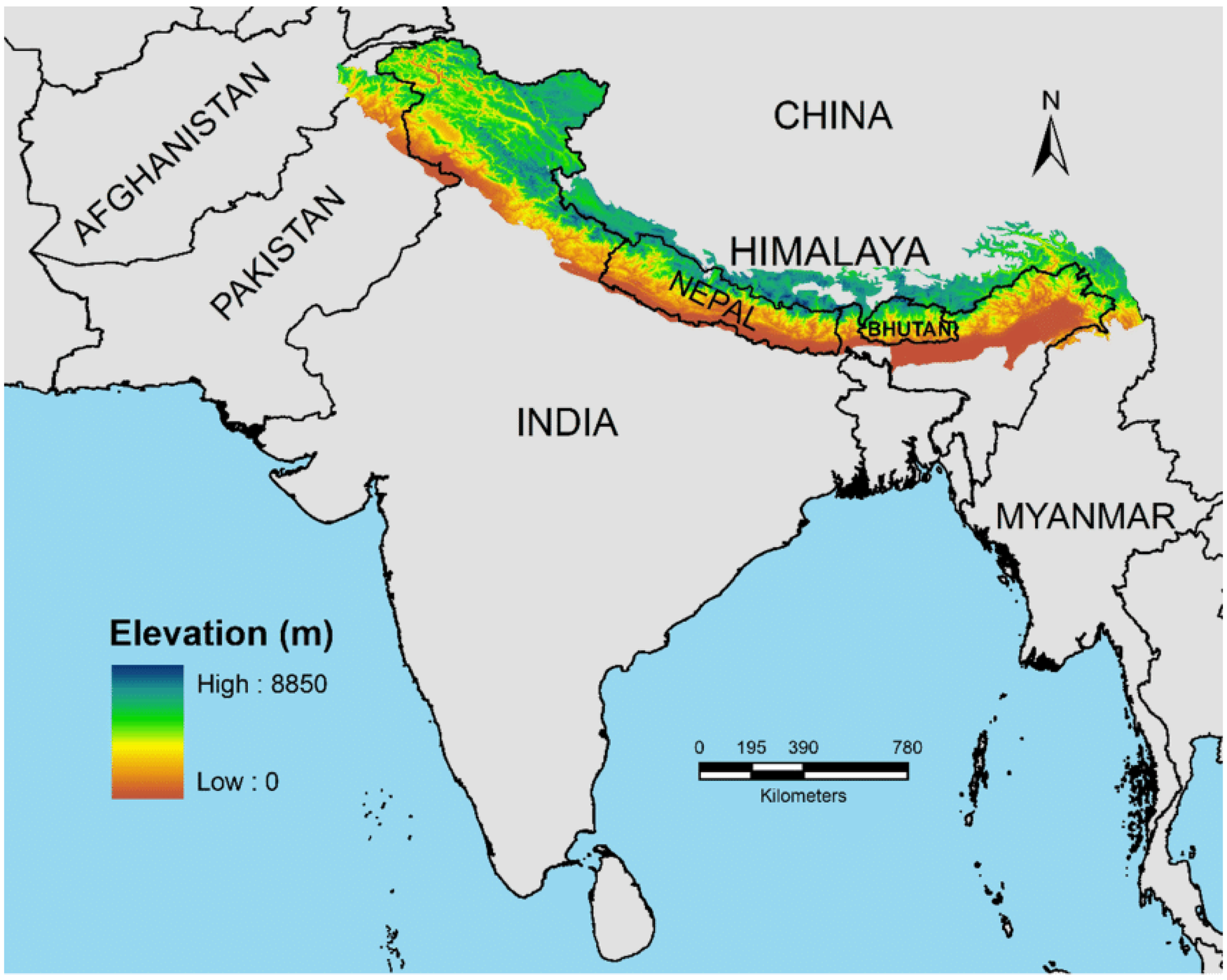

Figure 1: This is a digitally drawn map that highlights the number of countries the Himalayas pass through. "Spatial spread of the Himalayan mountain system across seven nations." Manish and Pandit (2018), CC BY 4.0.

Since the range passes through multiple countries, the cultures there are largely isolated. People have lived there since ancient times, and the indigenous population generally falls into one of three groups: Hindu, Buddhist, and Islamic. Because of the isolation that living in the Himalayas brings, the population demographics are

very different from Jammu and Kashmir – the Indian region where the Himalayas are located – as a whole. While the region is about two-thirds Islamic (Kirk & Akhtar, 2019), the mountains themselves are nearly equal parts Islamic and Buddhist, with a minority Hindu population (Bishop & Chatterjee, 2020). The population density in the Himalayas is also much smaller than the majority of the country (CIA World Factbook). Culturally, the Himalayas are the home of sacred places for multiple religions. Many Buddhist monasteries can be found in the region, and a monastery located in Bhutan has been thought to be the local birthplace of Buddhism (Cantor, 2017). Additionally, Hinduism has long personified the mountains as "Giriraj Himavat," the king of all mountains (Dallapiccola, 2002).

The Jammu and Kashmir region is an underdeveloped Union Territory along the Himalayas. Much of the region's economy is dependent on a diverse range of agriculture due to the distinct types of landscapes present. They grow mostly summer crops, including rice, corn, millet, pulses, cotton, and tobacco along with a wheat and barley as spring crops (Bishop & Chatterjee, 2020). The region is also rich with silk and fruit cultivation, most from the breeding of the Kashmir goat and farming from orchards within the Vale of Kashmir (Bishop & Chatterjee, 2020). These crops and textiles make up most of the state's $1.56 trillion GDP, as well as being supply goods for cities within the region itself (India Brand Equity Foundation, 2020).

Figure 2. Above is a map showing the location of the Jammu and Kashmir region with respect to Pakistan, India, and China. The map also illustrates the extreme terrain within the area that makes agriculture so diverse and unique. "Kashmir region", United States Central Intelligence Agency (1990), Library of Congress, Geography and Map Division, Public Domain.

This agricultural industry is the most susceptible to climate change within the region. Meteorological data from the region shows an annual decrease in summertime precipitation of about 20mm as well as an increase mean temperature of around 0.75 degrees Celsius (Rasool et al., 2018). This change in rainfall and temperature changes the agricultural properties of the some of the regions inside of Jammu and Kashmir, leading to lower crop yields (Rasool et al., 2018). As a result, many farming regions within the state are

changing from agriculture to horticulture, where a larger variety of crops are grown with a reduced yield.

The state of Jammu and Kashmir is considered a low-income country because of its lack of major industry and its population's quality of life. The only major industry within the region, besides agriculture, is their traditional handicraft industry, which is encompassed by the skills of weaving, pottery, and basketry (India Brand Equity Foundation, 2020). While this production of goods does employ 340,000 people from the Jammu and Kashmir region, it does not provide a large income, with 67.4% of households reporting that their highest paid member makes less than 5000 rupees, or $67.59 (Government of Jammu and Kashmir, 2017).

Jammu and Kashmir's proximity to the Himalayas gives the region a large and reliable source of water. Most of the water for the region comes from rivers, such as the Jhelum, Indus, Chenab, and Tawi river, which originate from glaciers and lakes within the mountain range (Ministry of Environment and Forests Government of India, 2016). All these water resources lie within the Jammu and Kashmir region and do not have to be imported. The previously mentioned rivers also have the ability provide a large and renewable energy output that could supply the energy for the region and India as a whole. India is mostly powered by fossil fuels, more specifically, coal, petroleum, and biomass, which account for 91% of all energy production, which can be seen in Figure 3 (U.S. Energy Information Administration, 2020). However, using hydroelectric power, the Tawi River alone could generate 23 MW of power, helping to lessen the severe effects of climate change created by the energy habits of the rest of the country (Ministry of Environment and Forests Government of India, 2016).

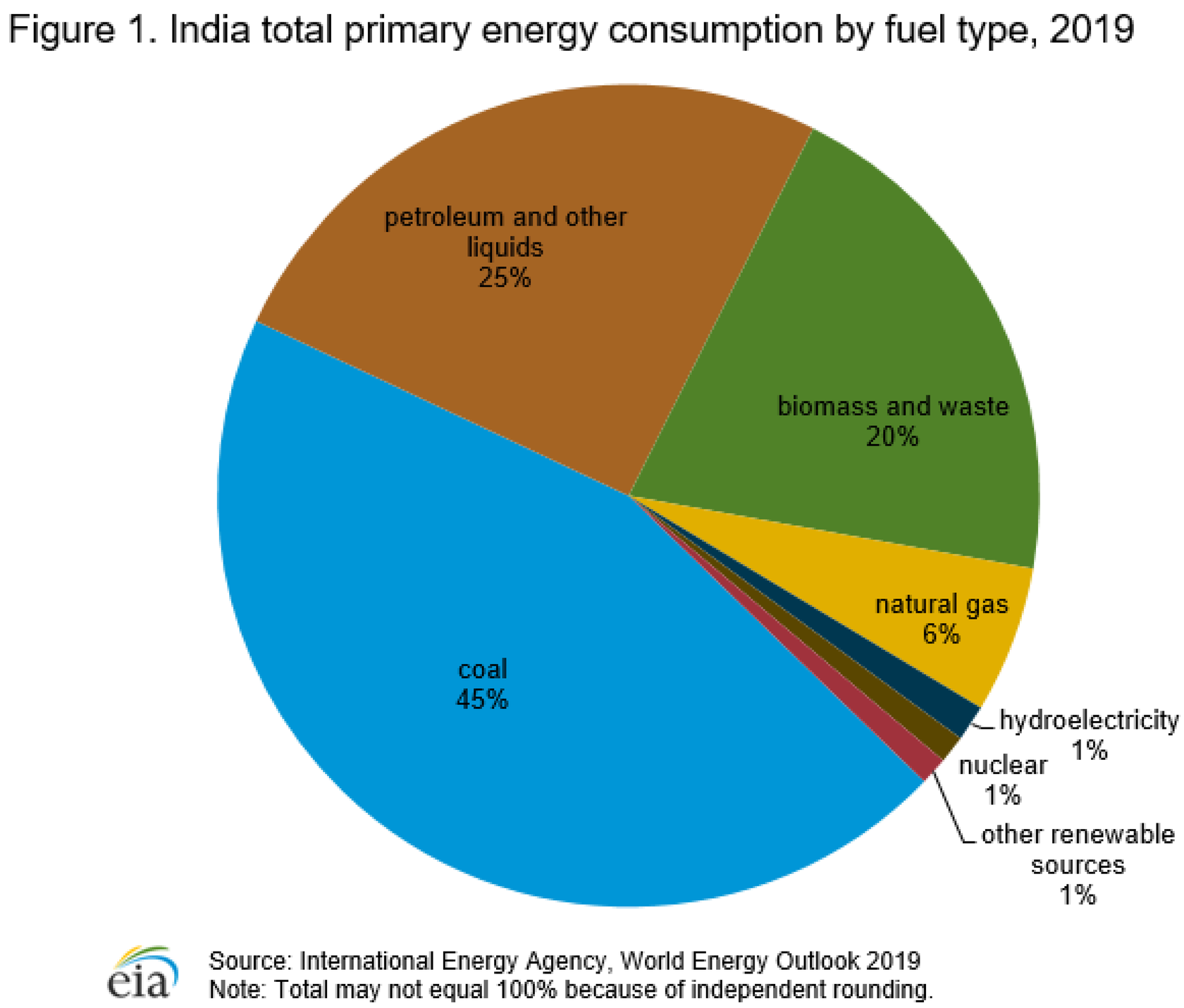

Figure 3. The pie chart above represents the sources of energy for the country of India during 2019. All their energy comes from fossil fuels leaving only a small percentage from renewable sources. "India total primary energy consumption by fuel, 2019", International Energy Agency, Public Domain.

The general climate of the Himalayas matters to more than just the mountains themselves. Seasons in this region are different from those experienced in most of the world. Instead of winter, spring, fall, and summer, they have a wet and a dry season that switch when the monsoon wind changes directions. During colder months, the wind blows down from the northeast bringing dry air but then during the warmer months it blows up from the southwest bringing rain (Shanmugasundaram et al., 2018). Different parts of the Himalayas experience the wet season at separate times of the year. The height of the mountain range takes much of the moisture out of monsoons moving north, leading to wet conditions in India but

drier, arid conditions in the country of Tibet (Bishop & Chatterjee, 2020). Four types of ecosystems are present on the mountain. The base of the Himalayas is made up of tropical rainforests, followed by more typical seasonal forests. Higher up are coniferous forests, composed of pine and yew, and finally at the highest elevations are grasslands and shrublands (PBS, 2020). Each zone is determined by elevation, as elevation determines not only general temperature, but also type and amount of precipitation. As a result of these different zones being relatively close, the Himalayas hold great biodiversity. Nepal, a country nearly entirely covered by the Himalayas, highlights this; despite the country making up 0.1% of the global land mass, the region holds 2% of the world's flowering plants and 8.9% of the world's birds, as well as nearly 4% of the world's mammals (Paudel & Bhattarai, 2011). Therefore, any change in climate would not only devastate human populations in India, but also affect massive amounts of plant and animal life. Their central location, multiple large river basins, and thousands of glaciers make the Himalayas a crucial part of all of Asia's life.

Jammu and Kashmir are in danger of losing critical resources and suffering drastic changes to the current climate that they rely on. An increase of one or two degrees Celsius by 2050 in this region is likely, which would lead to more inconsistencies in the monsoon, with an overall decrease in yearly precipitation (Sachidananda, et al., 2018). Agriculture yields are expected to decrease due to droughts, leading to more food insecurity and malnutrition. With less water, hydropower plants will be less effective, decreasing energy production. Drier conditions will allow more forest fires to rip through the trees, not only destroying resources for humans but also harming the unique biodiversity of the Himalayas. More climate related deaths will occur each year due to intense weather events, malnutrition, or lack of water (Sachidananda, et al., 2018).

So, what can be done to protect the state of Jammu and Kashmir from these horrible effects? To start, innovative technologies would have to be implemented to better the storage, distribution, and use of water. More effective irrigation methods that conserve water

could be used to reduce the strain that agriculture puts on freshwater resources. This could include drip irrigation which slowly drips water onto crops to ensure every drop gets soaked up by the plant (Shock, 2014). Diversifying the types of crops grown would provide a reliable yield each year even if diseases, droughts, or pests, wipe out some of the susceptible plant species. New committees or programs would have to be created to manage forests, wildlife, and watersheds as well as protect the diverse ecosystems (Shanmugasundaram et al., 2018). One such program that proactively supports the protection of Himalayan ecosystems is the Indian Himalayas Climate Adaptation Programme. A method this group uses to help protect the Himalayas is teaching courses such as glaciology and other related topics to young researchers and scientists, encouraging them to pursue research into Himalayan climate change (IHCAP, 2018). Since the region is very underdeveloped and lower income compared to the rest of India, a lot of government funding and knowledge is required to implement these plans. Luckily, India has been preparing for this and, under the National Adaptation Fund for Climate Change, has given grants to Jammu and Kashmir to fund agricultural adaptations (Sachidananda, et al., 2018). To truly save this region and its diverse wildlife, the rest of India and the world would have to adopt more sustainable lifestyles and focus all its efforts on fighting against climate change.

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12. Fiji

By Frank Ford, Katharine Miller, and Gabe Ward

Abstract: Fiji is a nation of tropical islands in the Pacific Ocean. With its beautiful beaches and lush biodiverse rainforests, it is very little wonder why Fiji is a vacation destination almost everyone has heard of. However, Fiji is much more beyond a beautiful travel destination, it is also a developing nation which faces a very real, and potentially devastating, threat brought about by climate change. Fiji is made up of islands with almost 90% of the population residing on the coast, thus, most of their infrastructure and population is susceptible to sea level rise. This has already started to effect specific communities, in early 2014 residents of Vunidogoloa village were forced to relocate due to increasing effects of climate change. Rising sea level was not the only factor in this relocation effort, as impacts of climate change in this region also include increased storm strength, increased likelihood of flooding, and decreased precipitation. Furthermore, the food system of Fiji is especially vulnerable as it is heavily reliant on importation of low-quality high calorie food, and the agriculture is shifting increasingly towards European style cash crop monoculture and away from traditional knowledge systems. Thereby increasing the vulnerability of crops due to extreme weather events and disease while also lowering the quality and nutritional value of the Fijian diet. In addition, the main

industry of Fiji, tourism, faces a dire future plagued by a decrease in travel to small island states due to more extreme weather in these areas and numerous other factors. Fiji is facing the dire impacts of climate change, and it will only get worse, unless something is done to remedy the situation soon.

Fiji Case Study

Fiji is an island nation in the South Pacific Ocean, consisting of 332 mountainous volcanic islands, approximately 110 of which are inhabited (see Appendix Fig 1 at end of chapter; Central Intelligence Agency, 2020). Fiji's overall climate is tropical marine, which means that it is quite humid and there is only a small amount of temperature variation between the coldest and warmest months (Kumar, et. al. 2013). The ecosystems present on the islands of Fiji are extremely biodiverse, consisting mainly of rainforests, freshwater swamps, mangrove swamps, and beach vegetation (Ash, 1992). All of the ecology of Fiji has traditionally played an important role in food security of Fiji as they acted as sort of a backup food source in case of drought or flood (Shah et. al., 2018). Ecologic diversity of Fiji is also a large draw for tourism, the largest industry of Fiji. However, these ecosystems have come under pressure in recent years, both from humans and natural events like tropical storms. One of the major threats to the rainforests is agriculture, as Fiji has moved away from traditional agriculture to a more European system, more and more rainforests are being cleared to make way for agricultural crops (Ash, 1992). Logging is another threat to the rainforests of Fiji; in fact, when Ash wrote his paper in 1992, it was estimated that all "production" forest would be logged by 2020,

which would leave approximately 2,700 sq km of unlogged forest on the islands of Fiji. However, this estimate proved to be dramatic, a 2011 estimate of the forest cover on Fiji was that around 55.7% of Fiji's land was forested (Central Intelligence Agency, 2020), nowhere near the figure that would be expected if rates of deforestation Ash based his estimate on held true; however, logging still poses a major threat to Fiji's rainforests. An additional effect of logging and forest clearing for agriculture is the decrease in biodiversity on the islands, because as the forest is cleared, the naturally diverse forest is often replaced with only one or two varieties of plants (Ash, 1992). The biodiversity of Fiji is important for a multitude of reasons, and thus important to conserve. The best strategy for conservation of the natural beauty and biodiversity of the Fijian landscape is effective forest management, ensuring that the biodiversity is preserved, namely by maintaining a high proportion of long-lived trees, as well as obtaining the necessary resources for continued success (Ash, 1992).

Figure 1. A picture of Vunidogoloa village after being relocated. Shown in the picture are houses built on stilts in order to reduce flood damage to the home. "The new village relocation site of Vunidogoloa", Piggott-McKellar et al., (2019), CC BY-ND 4.0

As global sea levels continue to rise, island countries such as Fiji are disproportionately affected. In early 2014, residents of Vunidogoloa village were forced to relocate due to increasing effects of climate change. Rising sea level was not the only factor in this relocation effort, as impacts of climate change in this region also include increased storm strength, increased likelihood of flooding, and decreased precipitation. Even though the houses in Vunidogoloa village were built on stilts to prevent flooding, as shown in Figure 1, floodwaters have become so high that these houses are being flooded anyway (McNarma, 2015). The Fiji government is planning similar relocation efforts and uses a process of identifying at risk communities and planning relocation logistics for them when these communities eventually need to move. A flaw in this process although is that many of the guidelines put in place for these planning procedures were a rushed response to climate change effects and could have negative impacts on the communities they are attempting to relocate. This could include not having the proper infrastructure to support such a heavy influx of residents to communities deemed safer. There will need to be massive amounts of funding from the government to bring the power grids, water supplies, housing requirements, etc. up to standard able to support the new residents. They will require things such as food resources to be imported before the new demand at local farms is met. This will lead to a decline in their economies, as these communities will drive the government into further debt and people will become poorer. These changes also harm the well-being of people in this communities. The place they are being forced out of is their home and contributes to their identity. A study conducted in Funafuti, the capital of Tuvalu, from 2009 confirmed that the land people there are living on holds deep cultural and sentimental value to them. The majority of residents there, when asked if they would leave, said no, citing "reasons of lifestyle, culture, and identity" (McNarma, 2015). These concerns should be considered when making plans on whether or not communities should be moved, and where to move them.

As an island nation, obtaining sufficient resources to maintain a growing population can be difficult. At this moment Fiji generates enough electricity to support its population; however, Fiji is barley generating sufficient energy and does not have additional energy to export. Thus in the future they may need to start importing energy, which could be made more expensive due to climate change—due to climate change potentially making energy more expensive to produce and transport, and more expensive to import (Central Intelligence Agency, 2020). Fiji relies heavily on rainfall for water to irrigate crops and provide water to people since much of their ground water is at least mildly salinized (Shah et. al., 2018). In addition to this, when analyzing Fiji's population and land area it can be determined that Fiji must rely on outside countries for some resources including food and water. Their agricultural density is around 570 people per square kilometer of arable land (Central Intelligence Agency, 2020). This number is almost five times larger than that of the US, which means that in Fiji five people rely on the same amount of agricultural land as one in the United States, indicating that Fiji must import resources to feed its population. Just as Fiji imports water, massive amounts of food are imported and exported each year (Shah et. al., 2018). The food that is imported as part of the Fijian diet is often lower-quality and nutritionally inferior food and makes up approximately 58% of Fijian caloric intake (Shah et. al., 2018). This system is both extremely vulnerable to climate change and a major driver of the high obesity rates in Fiji (Shah et. al., 2018).

With an agricultural system so reliant on precipitation, droughts have a huge effect on their agricultural economy. Recently, Fiji has been experiencing decreases in precipitation, leading to a decline in already limited freshwater reserves located on the islands. These droughts have many far-reaching effects, the most important of which are decreases in agricultural productivity, livestock, and livelihood. Fiji naturally has a wet period from December to April and a dry period from May to October, although these critical seasonal changes are becoming less predictable, and a recent El Niño period

from 2015-2017 exacerbated the dryness. In addition to this, Fiji experienced an unseasonal drought from October 2015 to February 2016 (Pearce, 2018). This is problematic as it doesn't give freshwater resources located on the islands the replenishment they need from rainwater. This leads to anxiety and stress among locals who are trying to care for their families by securing basic needs such as food and water. Prior to 2012, Vusama was completely dependent on rainfall for livestock and agriculture, with family groups maintaining 11 wells. All but one of the village's 11 wells ran dry by 2016, and the village now relies on water imported through a borehole that fills 10,000 L tanks that are then used to pipe water to individual houses (Pearce, 2018). The reason these wells ran dry is believed by locals to be caused by decreased rainfall, and a lack of maintenance of the wells after the borehole was introduced in 2012. This has negative implications for the villages water resources because the borehole alone is not enough to satisfy the villages water demands. These negative impacts could include water rationing, restricting water to only be used at certain times, and other regulations put out by the government. This will significantly change the way of life there and the economy there will suffer due to decreased water.

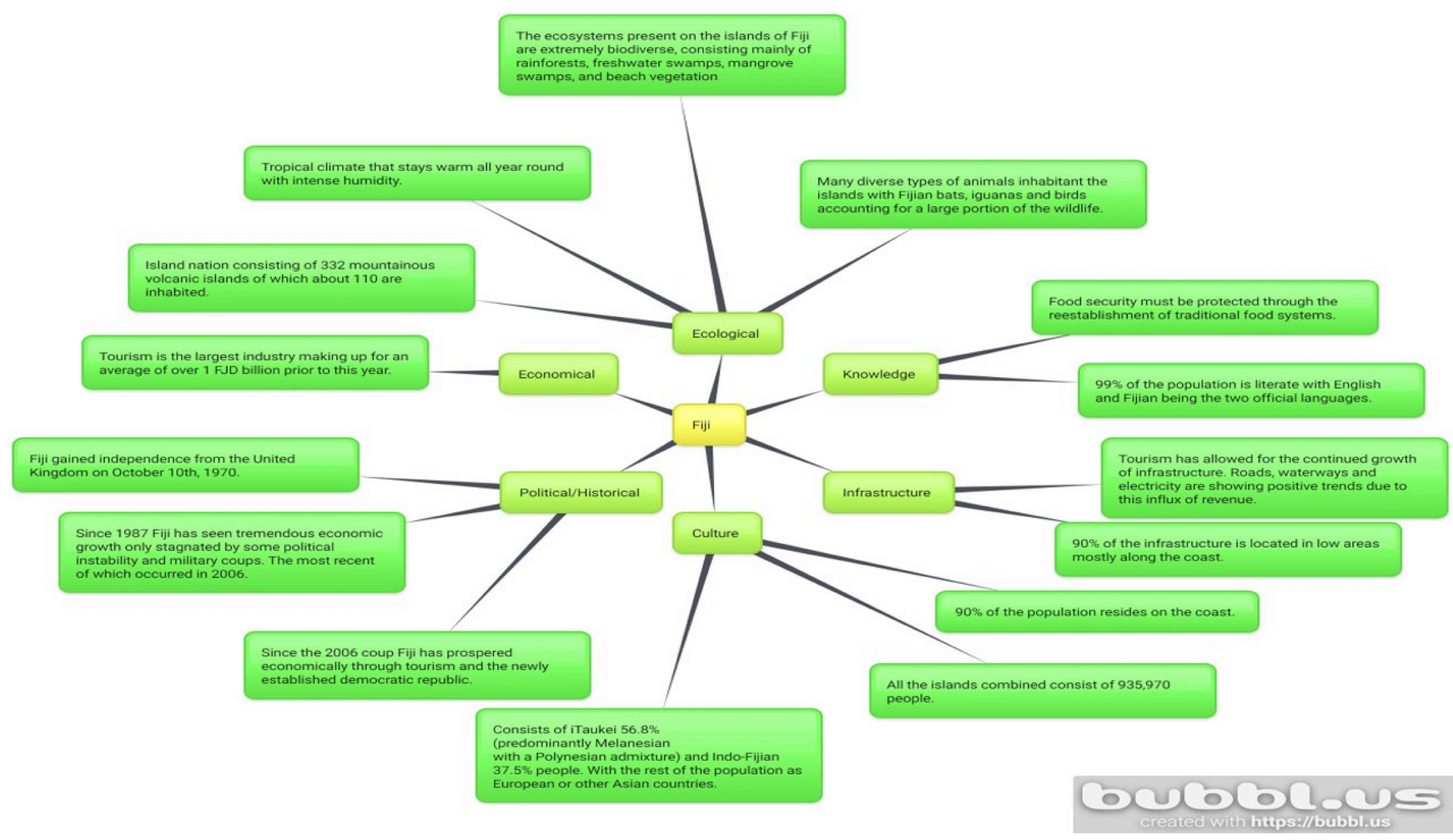
But how does a nation with about 23.3% of its land dedicated to agriculture have a food system so vulnerable to climate change (Central Intelligence Agency, 2020)? One major contributor is the type of agriculture practiced in Fiji. When Fiji was colonized, the style of agriculture was switched from polyculture, with multiple varieties of each food, focused on feeding people to monoculture focused on making money (Shah, et. al. 2018). As discussed in the Food Systems chapter, monoculture tends to lead to crops much more susceptible to diseases, climatic changes, and extreme weather events, an extremely worrying fact on tropical islands where diseases and extreme weather events are quite common and whose average temperature and number of extremely hot days are increasing (Shah, et. al. 2018; Kumar, et. al. 2013). The issue of food security is very important to deal with as even a 1% increase in food prices would be enough to push 1,000 Fijians into poverty

(Government of Fiji et. al., 2017). One of the best methods for combating food insecurity and making Fiji's food system climate resilient would be utilizing traditional knowledge systems to shift Fiji's food production, storage and preservation methods to a much more traditional approach (Shah, et. al. 2018). Important steps to achieving this are increasing on farm diversity, making local food both the more affordable and desirable option, and reestablishing the forests of Fiji as a backup food supply in case of a weather event which causes food shortages, like droughts or floods (Shah et. al., 2018).

The tourism industry has become the main industry of the island more recently. Once a sugar cane producing island Fiji now turns its resources to the tourism industry. Tourism has brought in almost double the amount of money for foreign exchange compared to sugar cane. This huge gap has only grown in recent years as visitors from the US, Australia, and the UK have led to a 6.2% increase of the industry (Becken, 2005). While Fiji's main industry has remained strong in the last decade it is anticipated to suffer as results from climate change begin to take full effect on the small island state. Almost 90% of Fiji's population and infrastructure are located on the coast in low lying areas which therefore will result in flooding and infrastructure damage due to rising sea levels. Sea levels are anticipated to rise 23-43 cm by 2050 and up to 1.03 m by 2100 (Becken, 2005). This would be devastating for the small island state because many insurance policies do not include damage done by activities due to climate change. Additionally, the money that would need to be poured into relocated infrastructure further inland would be enormous. Also, coastal erosion due to changing wind patterns is predicted to be devastating to the tourism industries beaches. In combination with more extreme weather and the increase in vector borne diseases resorts will be facing a decrease in tourism movement throughout the world. Since tourism is the main industry for Fiji, solutions are necessary to keep this island state economically strong. This has led to early planning from results in coordination with the government to not only mitigate the coming

changes, but additionally do their part to fight the problem. Resorts have already begun implementing eco-friendly habits in every room. They have become more aware that changes must be made in the way that business is conducted so that business may be conducted in the future (Ayala, 1999).

It has become apparent that Fiji is a perfect prototype for many similar island states. They have the resources to make changes that should and will hopefully be used by other islands to promote a better future. The future presents Fiji with a complex set of issues that if not met with urgency could be devastating to the country, however, preparation and planning will undoubtedly mitigate many future impacts that climate change will have on the small island state.



Appendix: Figure 1. Map of assets and vulnerabilities of the island of Fiji related to climate change.

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PART IV

IN SEARCH OF SOLUTIONS

The culmination of each first-year Great Problem Seminar course at WPI is the opportunity to conduct a team-based project that addresses problems focused on themes of global importance- in this case climate change. The final chapters in this text are a result of topics that teams selected that address a climate change angle. Each team took great care in the scholarly pursuit of defining a problem, researching the underlying causes, describing their project approach and methodology, presenting results, drawing conclusions while incorporating ethical, social, environmental, and other implications, and providing recommendations. Students incorporated their work into these chapters and via a poster presentation day that is open to the public. In these projects around climate change, we saw a clear pattern of students interested in a) indigenous rights and their connections to natural resources and b) shifting energy resources.

Chapter narratives from the student authors themselves:

Chapter 13 (Rigged for Oil Rigs): In the United States, there has a debate on whether to drill for oil in the ANWR (Arctic National Wildlife Refuge). Opening the Arctic for drilling will have many negative effects (on the Native Alaskan tribes, on migratory animals, and on global climate as a whole), and so it should be prevented.

Chapter 14 (Climate Change Impacts on Native Hawaiian Population): Indigenous Hawaiians are disproportionately affected by climate change due to their reliance on natural resources and cultural ties to the land. Actions like coral gardening and shoreline hardening are methods that will protect coral reefs and beaches which
provide money and resources to natives that allow them to survive and adapt their culture.

Chapter 15 (Destigmatizing Nuclear Energy to Decarbonize the

Worlds' Power Supply) pits the public perception of nuclear energy against a potential but misunderstood source of energy. Students debate the pro's and con's of nuclear energy and broadcast their findings to the readers.

Chapter 16 (Small Scale Carbon Capture Implementation and Utilization): The implementation of carbon capture on all scales is a viable path forward for the transition to renewable energy. The heat generation system at Worcester Polytechnic Institute provides a unique foundation for the local application of these technologies, where we believe large scale methods and devices can be derived from in the future.

13. Rigged for Oil Rigs

By Katherine Corbin, Nora Smith, and Gabriel Ward

Chapter Summary

Oil drilling in the ANWR would cause environmental damage, affecting the way of life of Native Alaskans by creating pollution and affecting migratory species, as well as upsetting major offsets of pollution. All this would occur with only a minor economic impact, as the amount of oil even in the area is unknown but estimated to be enough to power the economy for only 6 months. To prevent this, we aim to increase public awareness and partner with an advocacy group in order to create government change. The organizations we reached out to all prioritized uplifting the indigenous voice.

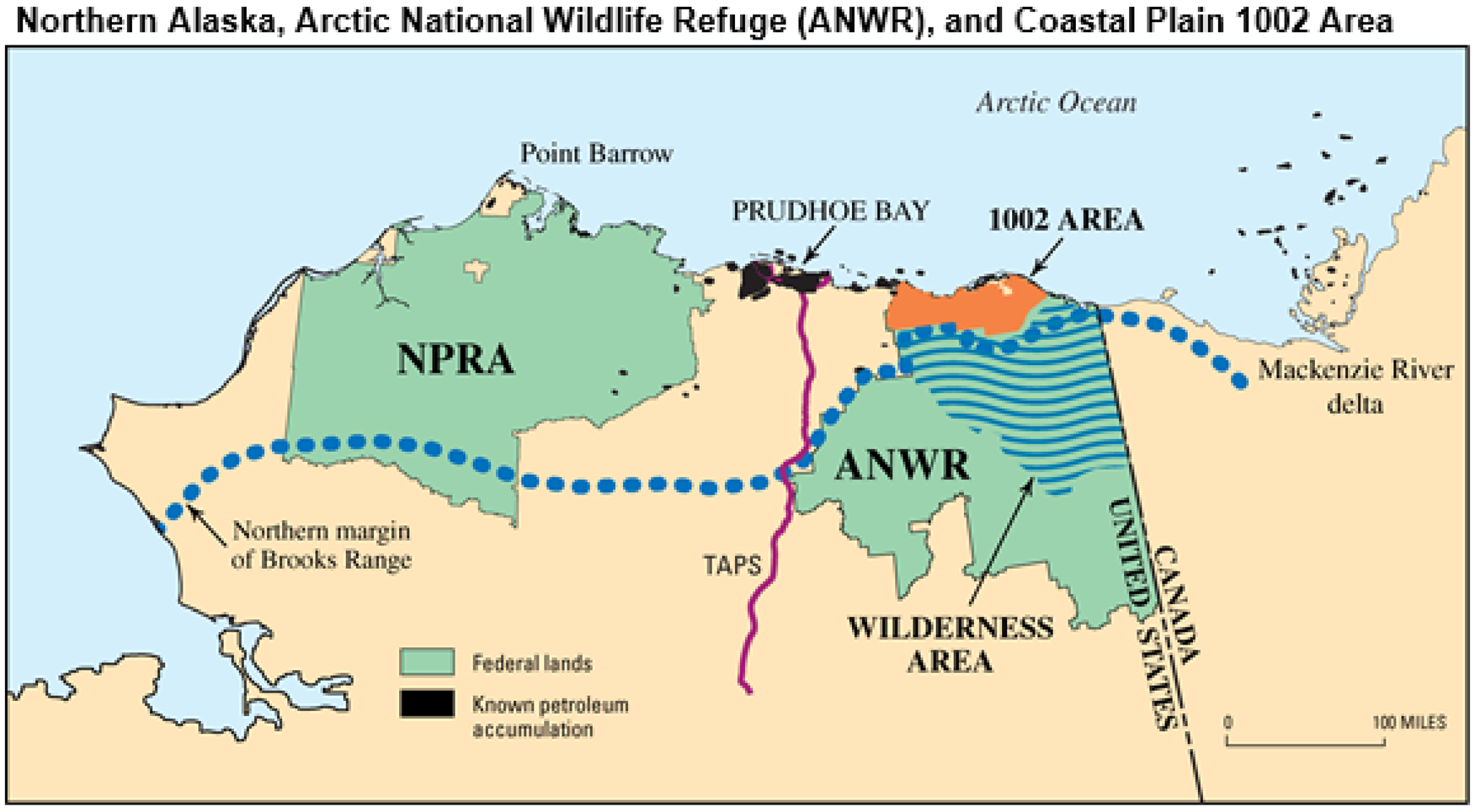

Figure 1. Map of northern Alaska showing the locations of ANWR, including locations of possible oil accumulations for drilling. "ANWR and known oil deposits in northern Alaska" USGS (2016). Public Domain.

Introduction

The **Arctic National Wildlife Refuge (ANWR)** is one of the last remaining untouched wildlife refuges, located in the northeastern region of Alaska and encompassing an area of 19 million acres. Known for its pristine environment, Indigenous people, and wildlife, this place carries a deep significance to the Gwich'in people who rely on the migratory patterns of the Porcupine caribou herd. Despite the hundreds of years spent living off the land, their home has come under attack in the past 50 years due to oil corporations, who believe there are somewhere between 600 million – 7 billion barrels of oil sitting beneath their sacred grounds. In addition to destroying the centuries-long way of life of the Gwich'in people, potential oil spills can wreak havoc on surrounding wildlife, migratory patterns of caribou herds will change, and local pollution will impact the surrounding ecosystem. Despite all the problems outlined here, many people still support drilling in the Arctic because media outlets backed by the oil industry fuel narratives that

encourage drilling. Due to the lack of readily available information, our paper focuses on raising awareness about the negative effects of drilling in the Arctic, and what can be done to prevent it.

Background

The American public is asking for change. In a spring 2020 survey, 79% of US adults said that looking into renewable energy resources is a higher priority than drilling to address the nation's energy concerns (Gramlich, 2020). It has become clear that the American public is not getting what they want, as corporations continue to lobby in favor of the fossil fuel industry. This entire movement started with the Reagan administration in 1986, as he was the first president to express interest in Arctic drilling (Standlea, 2006). However, when proposed legislation was brought to President Clinton about opening the ANWR on December 5, 1995 he decided to veto it saying that drilling would, "threat[en] a unique, pristine ecosystem in hopes of generating $1.3 billion in Federal revenues—a revenue estimate based on wishful thinking and outdated analysis. I want to protect this biologically rich wilderness permanently." The White House completely reversed this standpoint during Trump's presidency, who on March 28, 2017 decided to start leasing land in the ANWR to oil companies. Before this plan could come to fruition, President Biden placed a temporary ban on drilling in the Arctic during his first few days in office. This goes to show how uncertain the future of the ANWR remains, as Indigenous people are currently still seeking protection for their sacred lands. While the Alaska Native Claims Settlement Act of 1971 gave Indigenous peoples title a large land base, this act excluded regions that were known to hold the potential for oil development and, in exchange for the land given to them, all previous claims that would have granted Indigenous people far more land were terminated. In 2005, the Inuit of Alaska, Nunavut and Northwest Territories petitioned the Inter-American Commission on Human Rights, arguing that the USA, as a main contributor to anthropogenic climate change, was violating their rights to the use of land for subsistence, health, life, and security (Zentner, 2019). The petition asks specifically for

the commission to declare that the US, as the world's largest contributor of greenhouse gas emissions, is in violation of the 1948 American Declaration of the Rights and Duties of Man. The petition seeks to amend this violation by establishing limits on greenhouse gas emissions and cooperate with the community of nations, including the United States and Canada, to prevent anthropogenic climate change (Crowley & Fenge, 2005).

Protections for Indigenous people are not the only point of contention, from the 1970s-1990s the US underwent a change in how it views environmental policy. In the 1970s the US focused primarily on technical learning, which emphasizes legal solutions such as the Clean Air Act of 1970 (Fiorino, 2002). This preserves traditional standards of hierarchy and removes responsibility from other government branches. This focus started to change in the 1980s when attitudes during the Reagan administration shifted to conceptual learning, which means that the government would intervene less and look at environmental policies in more of a conceptual manner. This allowed for the separation of environmental goals from other political goals, creating debates and de-prioritization for the problems considered less important by those in charge. After the Reagan presidency, attitudes progressed from controlling pollution to preventing pollution. The 1990s also signaled an era in which a shared responsibility to protect the environment was developed that emphasizes connection and contact between "participants," or those affected by what happens to the system and those that cause changes (Fiorino, 2002).

Looking at drilling in the ANWR from an economic perspective does bring about some fleeting benefits. These include a temporary decrease in the price of oil, less reliance on imports which makes oil less expensive, and temporary job opportunities. A particular area under contention is the 1002 area. This is a biologically important area, estimated to contain 4.24 billion (with a 95% certainty of existence) to 11.8 billion barrels of oil (with a 5% certainty of existence; Kotchen & Burger, 2007). However, these are rough estimates. This means that there is a chance the return on

investment of drilling there could be very little when considering oil and expenses used for extraction. And even in a best-case scenario, the oil extracted would not provide the United States with energy for long (Kotchen & Burger, 2007). The rate of oil consumption in United States during 2019 was 20 million barrels per day, which comes out to 7.3 billion barrels per year (US Energy Information Administration, 2021). At this consumption rate, the barrels of oil gained from the lower estimate of oil supply would only provide enough for 212 days of power.

Even with the minor economic benefits, there are major environmental impacts with lasting effects. Opening the ANWR for drilling will increase emission outputs by between 0.7 and 5 million metric tons of carbon dioxide. The high end is about 12% of Alaska's annual emissions (Aton, 2019). This will contribute to further warming the Earth's climate. In addition to this, migratory animals will be the most affected, as both the drilling and the infrastructure could disrupt their patterns of movement. The Porcupine caribou are the most prominent example, as there are people who rely on their migration being unchanged, but there are many species of migratory birds, including snow geese and bald eagles, that will be affected as well (Arctic National Wildlife Refuge, 2014). In addition to this, less is known about the impacts on other species but it can be determined that massive amounts of habitat loss will occur. Human disturbances will cause changes in migratory routes for species like caribou that reside in the area. These disturbances will also prevent species from reaching parts of their land and prevent them from accessing the available vegetation (Plante et al., 2018). Many animals, birds in particular, are significantly impacted by oil spills that are likely to occur if the ANWR opens for drilling. ANWR drilling will also promote air pollution and greenhouse gas emissions, thereby perpetuating our already self-destructive dependency on fossil fuels. Lastly, drilling ruins the natural scenic beauty of the area. Due to the impacts that drilling would have on the Arctic, actions must be taken to prevent drilling in the Arctic and to inform people of the situation.

Methodology

Our goal is to learn how the US has approached the topic of Arctic drilling through different policies, as well as spending some time looking at drilling through the lens of Native Alaskans. We are also aiming to partner with an advocacy organization to advocate for policy change in favor of the environment. In order to identify different advocacy groups, the group contacted different organizations to learn more about the issues and the missions of the organizations. The group looked into contacting the Audubon Society Alaska, NRDC (National Resources Defense Council), Native Movement, and Richard B. Slats from ARCUS (Arctic Research Consortium of the United States). The group had planned to interview representatives of these organizations and additional research was done to see what work these groups have accomplished and what they have planned.

In addition to contacting organizations, the group also conducted individual research on the effects of drilling in the ANWR. The method used for this research involved utilizing databases such as the WPI George C. Gordon Library, and each team member had specific kinds of effects of drilling in the ANWR to investigate. These effects included economic benefits and drawbacks, environmental impacts, impacts on Indigenous lands and people, and political perspectives on drilling.

The group used a decision matrix in order to decide what the best possible solution to solve our problem was (Figure 2). This decision matrix helped us look at different problems that would be impacted by drilling and helped us look at how our different possible solutions would impact these problems. Our first solution was to raise awareness of Arctic climate shifts in order to inspire change. We thought that partnering with an advocacy group against Arctic drilling would help shift the views of the public and work towards making bigger changes. Our second possible solution was to investigate options for greener drilling. While this option may not

be ideal, it is important to look at other possibilities if drilling in the Arctic cannot be prevented by law. Our third option was to encourage the Green New Deal. This option would help encourage policies that could protect the Arctic from drilling, as well as shift overall climate justice. In the decision matrix the problems were scaled from 1 to 3, with 1 being the lowest impact and 3 being the highest impact. The solutions were then compared to each problem in order to look at how that solution would impact the problem. This was done with number values as well with 5 having the most impact and 1 having the least impact.

PROBLEMS > **SOLUTIONS** V	Impact on Endangered Species - 3	Physical Ecosystem Impact - 1	Economic Impact-2	**OUTPUT**
Raise Awareness	3x5=15	1x4=4	2x2=4	23
Greener drilling	3x1=3	1x2=2	2x4=8	13
Encourage Green New Deal	3x5=15	1x4=4	2x5=10	29

Figure 2. Decision matrix that guided best possible solution decisions.

Findings and Results

Through our research, we found that drilling in the ANWR has many far-reaching effects that impact the economy, wildlife, and Indigenous communities. From this, we have determined that drilling in the ANWR is not worth the estimated 600 million to 7 billion barrels of oil contained within the ANWR. This gives us a mean estimate of 3.5 billion barrels that can be extracted from the ANWR, which is predicted to power the US economy for roughly

6 months (Standlea, 2006). The effect that this temporary increase in oil production will have is modest, attributing to about a 1% decrease in oil prices.

The tradeoff for drilling in the ANWR far outweighs the short-lived benefits. Indigenous people, particularly the Gwich'in people, have relied on the Porcupine Caribou Herd for sacred hunting practices for hundreds of years. Drilling would disrupt the migration patterns of this herd as well as other wildlife species, putting an end to a critical piece of Gwich'in culture. The impact on wildlife includes more than changes in migration patterns; if the ANWR were opened for drilling, 69 of 157 bird species found in the area could be at particular risk, and the Bering seal population which is already predicted to be extinct by 2095 would see an even more rapid decrease in population size. It is predicted that drilling in the Arctic will increase emissions between 0.7 and 5 million metric tons of CO_2 (Aton, 2019). This increase in local emissions will cause sea ice to melt even faster, contributing to the decline in the Bering seal population. This loss of this wildlife will cause a chain reaction of population decline in wildlife, as species such as sharks rely on the seal population for hunting. One of the most concerning side effects of drilling for oil are potential oil spills, which have a significant effect on birds as crude oil and tar that gets stuck in their feathers inhibits their ability to fly, effectively killing them. With these concerns in mind as well as the fact that we as a nation are beginning to move away from fossil fuels, drilling in the ANWR is hardly practical and will only provide a short-lived supply of oil.

Conclusion and Broader Impacts

The primary implication of our findings is how far-reaching the environmental negatives of oil drilling here would be in comparison to how small and short-term the economic positives would be. The local environmental impacts cannot be underestimated either: thousands of Native Alaskans depend on migratory animals like the

Porcupine caribou and whales in order to keep food on the table and cultural traditions alive. But if that wasn't enough, the environmental impacts go deeper still. Upsetting the land in this area disrupts a major carbon sink, releasing previously trapped CO_2 into the atmosphere and removing an area where new emissions could have been absorbed (Miller, 2020). Snow and ice need to be removed for infrastructure to be built and trucks to drive, weakening the strength of the **ice-albedo feedback loop**, which would raise the temperature of the planet even further. Meanwhile, the cause of these long-term environmental effects is a short-term boost to the United States economy. To weigh 6 months of oil against decimation of an important piece of natural climate mitigation and find the oil more valuable is something we hope to turn people away from.

We hope this research shines some light on a highly contested issue that not many people know the specifics of. If we can help people understand the numbers behind the financial gains that are to be had as well as show the environmental losses, we feel that more people would be in favor of stronger government protection for this land. In a theoretical model showing the relationship between social media and an individual's personal involvement with a movement, likelihood of protesting is directly correlated to how often an individual sees others active in the movement (Little, 2016). The more people are outspoken about protecting this land, the more likely it is that more people will join them. This kind of solution can also be applied to any environmental issue. While it is not as direct as implementing a technology or inventing something new, getting more people invested in saving the planet is never a bad thing, and change starts with individuals.

Recommendations

Our research has led us to three different solutions, each with different pros, cons, and steps to implementation. Solution one is to

raise public awareness of the issues that would arise from drilling, putting pressure on corporations and the government to not drill and prevent drilling respectively. Solution two is implementing the Green New Deal or, more generally, introduce more government regulation on drilling to make it safer and less destructive. Finally, if drilling is not fully preventable, solution three is to require companies to implement greener drilling technology in order to lessen the impact of any drilling that occurs in the Arctic.

When reviewing our solutions, we looked at the impacts these solutions would have. The group looked at how these solutions would impact endangered species, the physical ecosystem, and the economy. Oil drilling would have an impact on the calving grounds of caribou and the roosting sites of migratory birds, damaging populations and creating food scarcity for Indigenous tribes. Additionally, it is estimated that opening the ANWR to drilling would cause Alaska's total emissions to rise by 12% (Harsem et al., 2011). Finally, this is all supported by the fact that there is an unknown amount of oil contained in the ANWR, meaning that a known amount of devastation would occur for an unknown amount of oil.

These solutions are the best possible solutions because they encompass both the best possible solution (drilling is no longer allowed in the area) and the most realistic solution (drilling continues with greener technology). As with any environmental problem, there are no "right answers" here. What would be best for local Indigenous tribes and animals would be to ban drilling there completely, but the Alaskan economy is heavily reliant on oil. Stricter government regulation would keep drilling safer and potentially completely discourage it, but there is very little chance of that happening while oil companies continue to spend millions lobbying politicians. Greener drilling technology seems like a happy medium: corporations still get their oil money, but not without having to consider the environment and the local peoples first.

Native Alaskan populations benefit from a ban on drilling as they will get to keep their land and sacred hunting practices. Wildlife in the ANWR will also benefit from a ban on drilling because oil

spills, habitat loss, and increased local warming from emissions in the area will lead to a decline in wildlife populations, alter migration patterns, and already endangered species may go extinct. The only drawback to not drilling in the ANWR is that the potential oil in the area can't be used to boost the US economy, although the effect drilling would have would be short lived.

Implementation

The solution we chose to try to implement is to raise awareness. In order to do this, we will reach out to an advocacy group that aligns with our goals of prioritizing Indigenous Alaskans and focusing on the environment. This will be done after we research multiple different advocacy groups, their goals, and their prior work. Once we have found a group, we will get in contact with them, as well as seek out individuals within the organization that can provide advice and recommendations on how to best further the group's accomplishments. The group will continue researching and contacting new groups until we receive a response from an organization that we would like to partner with. A successful collaboration would allow us to become more educated in the proper way to go about our next step: advocating for change.

In order to advocate for change, we plan to conduct further research on the organizations of our choice to learn more about changes they have made to local and global communities and their successes on a local and federal government level. We also plan to conduct an interview with a representative of the organization to find out more details about their plans. This will help us formulate our own action plan to spread awareness as well as educate us on potential challenges we may face. The reason we feel partnering with an organization is so important for this step is because of our position in the world. We are three white students, raised in the continental United States. We can do research and read first-hand accounts, but we will not be able to adequately advocate for what is

truly needed by the people in Alaska unless we seek out what they have to say. Every voice matters, but a misinformed voice may do more harm than good.

We will then ask what we can do to help raise awareness and assist with their activities once we have partnered with the organization. With the resources and guidance provided by the organization, we hope to start educating others in the same way the organization educated us: by providing us with a better understanding of the issues and a better knowledge of what we can do to solve it. If COVID permits it, we also hope to be involved in potential marches and protests supported by our organization.

We will see success with this solution if we partner with an advocacy group and assist them in achieving their goals. Through this we hope to convince others to join or support the advocacy group we choose to work with. The ideal goal would be to see policy changes as a result of our actions, which would include a range of things like a ban on drilling, to increased regulations that would make drilling a greener process. Even if we do not achieve this ultimate success, our success includes increased awareness through education, which we achieved simply by giving our presentation at the end of the term. While the three of us do not have much sway in governmental change, we hope that our efforts combined with an advocacy group contribute to changes in attitudes towards drilling in the ANWR. For every person we can make more aware, the less likely they will be to support drilling in the ANWR, and this could lead to real government change.

See Appendix 1 for the infographic of this project used during Project Presentation Day.

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Glossary

National Petroleum Reserve Alaska (NPRA) – Area of land in Alaska that is owned by the federal government of the United States and is managed by the Department of the Interior, Bureau of Land Management.

14. Climate Change Impacts on Native Hawaiian Population

by Isabella Clowes, Elizabeth Dahlberg, and Katharine Miller

Abstract

The Hawaiian archipelago is vulnerable to climate change due to the low elevation and large population which is extremely reliant on the ocean, natural resources, and tourism. Native Hawaiians will suffer most from climate change because they depend on natural resources and reside on the coast. Climate change in Hawaii causes sea level rise, coastal erosion, tropical storms, and coral bleaching. To fix these issues, the entire planet needs to work together to reduce fossil fuels. However, Hawaii has implemented some strategies that have reduced the consequences of climate change.

Picture of a rainbow over Diamondhead National Park in Oahu, taken from the top of the Diamondhead volcano. Credit K. Miller

Introduction

Our project addresses the main issue of how Native Hawaiians are being impacted by climate change. The main questions that guided our research were, what are the social, economic, and cultural issues the Native Hawaiians are facing? What are some solutions to help the Native Hawaiians?

Think of an island paradise with clear water, white sandy beaches, tall palm trees, and coral reefs, existing all in one place. This is Hawaii, a place anyone would dream of visiting. Now imagine all these things are damaged extensively by climate change. Hawaii faces this grim reality unless something is done to decrease the rate of climate change and mitigate the damages that climate change has caused in Hawaii. Climate change directly caused by humans has been getting worse since the industrial revolution (Murakami et. al, 2013). Humans rely on fossil fuels which spew out carbon dioxide

and other greenhouse gases which trap in the sun's light. The air temperature rises causing coral bleaching, more extreme weather, and rising ocean levels as the ocean warms and expands (Murakami et. al, 2013). Warming of the oceans will harm fish populations and deprive residents who rely on fish for their income or diet (Cavenave & Llovel, 2010). The lifestyles of Native Hawaiians could significantly suffer in the near future as these problems continue to worsen.

Background

The first Hawaiians were descendants of Polynesian travelers originally from the islands of Tahiti and Marquesas (Andrade & Bell, 2011). During the 1820s, missionaries, Europeans, immigrants from the United States and Pacific, and ethnic groups from China, Japan, Puerto Rico, the Philippines, and Korea came to Hawaii. They created a different way of Hawaiian life, decreasing the Native Hawaiian populations. The native Hawaiian language was almost extinct, but the younger generations were able to keep it alive (Swenson et al., 2021). Tourism in Hawaii exploded, and Hawaiian culture was boosted into what we recognize today, creating festivals such as Lei Day and the Aloha Festival for tourism and profit (Andrade & Bell, 2011).

Being a set of secluded islands reliant on tourism with a unique culture, Hawaii is especially vulnerable to climate change. The main issues the islands face include sea level rise, increase in tropical storms, and coral bleaching, which put huge strains on Hawaiian society (Figure 2). Hawaii's vulnerability is the reason why finding solutions to these problems is vital.

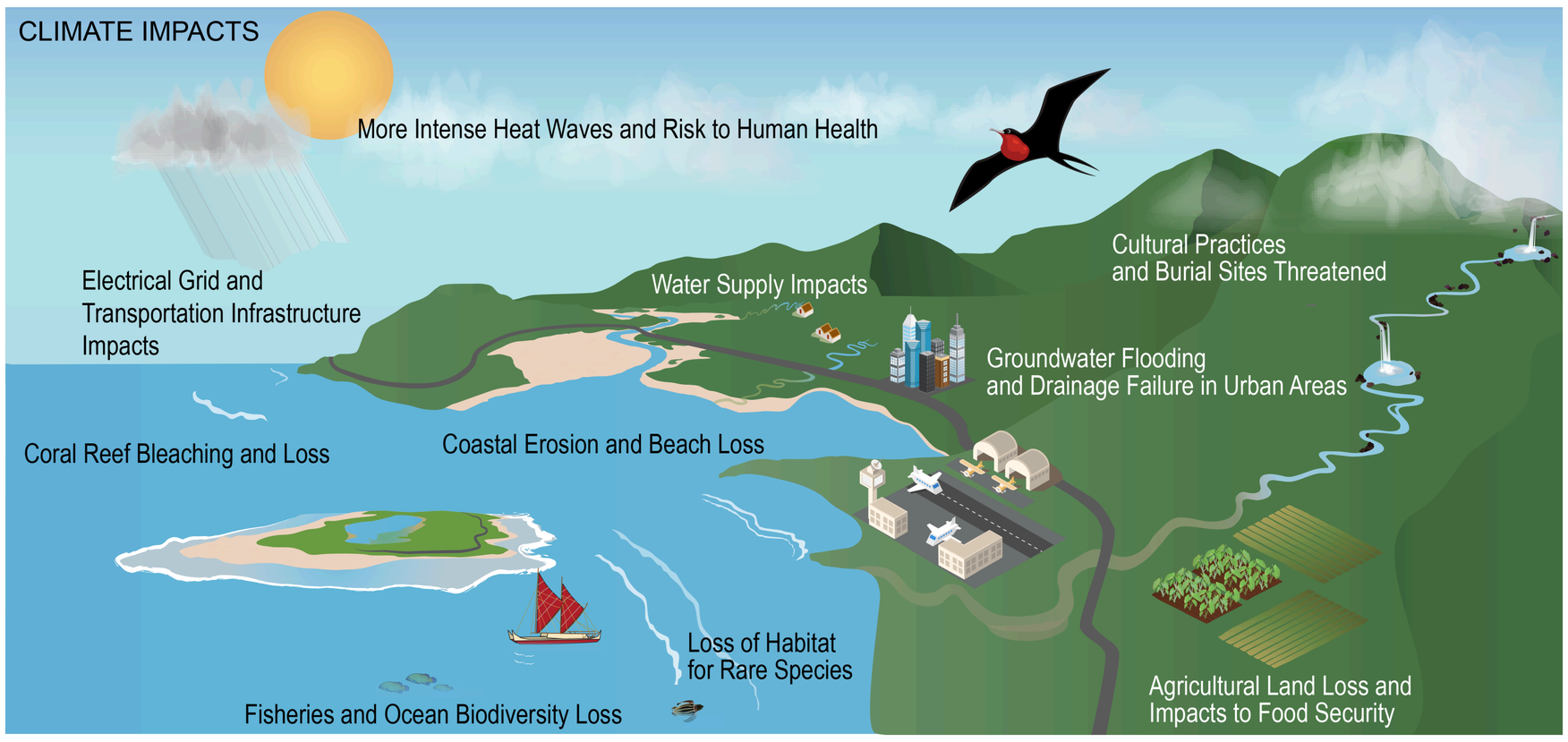

Figure 2: Graphic showing the many issues that Hawaii faces in regard to climate change. Figure courtesy of Keener et al., 2018.

The issues created by climate change are experienced all over the islands, yet some residents will suffer more than others. Native Hawaiians are at a higher risk of suffering and loss from climate change because their religion and culture depend on natural resources (Ancheta, 2017). The traditional Native Hawaiian religion believes that all life originated from the ocean; therefore, they respect the ocean and rely on the life sustaining resources it provides (Andrade & Bell, 2011). People of other cultures in Hawaii do not have as significant ties to the ocean, allowing them to reside inland where the impacts of climate change are less severe (Ancheta, 2017). The decline of natural resources, and many pieces of Hawaiian culture create economic problems for Hawaii.

Tourism is an integral part of Hawaii's economy as many tourists visit to connect with nature, lounge on beaches, explore the ocean, and experience the Native Hawaiian culture. Tourism in Hawaii greatly exploits the Native Hawaiian culture for profit which is detrimental and degrading to the people (Desmond, 1999). The image of an "ideal Native" is perpetuated with an exotic look and warm welcoming demeanor to appeal to tourists. Traditional clothing is sexualized and they are put on display as attractions. Despite the exploitation, Native people get sucked into the tourism

industry because it offers many jobs as performers or tour guides. Native Hawaiians become reliant on the industry when they cannot find jobs elsewhere and it creates a cycle of ill treatment and dependence (Desmond, 1999).

Hawaii will lose much of the tourism industry as the beaches erode from sea level rise and tropical storms (Anlauf et al., 2011). It is reported that Hawaii earns about 60% of their tourism income off coral reef activities and recreation (NOAA, 2020). Coral bleaching and disappearing beaches will deter tourists, removing an integral part of Hawaii's economy. Coral bleaching occurs when the ocean warms too much, forcing coral to spew out symbiotic algae that lives within its tissue and provides oxygen (Lirman & Schopmeyer, 2016). The coral is left colorless and more vulnerable to damage or disease after being bleached. Tropical coral reefs exist in warm water that regularly reaches temperatures above the maximum temperature of coral's tolerance, therefore coral in Hawaii is much more susceptible to bleaching (Anlauf et al., 2011). Hawaii has already lost many of its reefs and it is predicted that the Earth might lose 70% of its reefs within forty years (Anlauf et al., 2011). Many fish species or other organisms such as lobster rely on the coral for food and protection (NOAA, 2020). Without healthy reefs, their populations suffer and there is less fish to catch, decreasing the food supply and income of fishermen.

One of the most severe and potentially deadly effects of climate change on the Hawaiian Islands is the increasing frequency of tropical storms and cyclones. Globally, the frequency of tropical cyclones is predicted to decrease while the average and maximum severity of tropical cyclones will increase (Murakami et. al, 2013). However, this prediction varies regionally. Climate models have predicted a statistically significant increase in tropical storms and cyclones that will affect the Hawaiian Islands (Murakami et. al, 2013). Tropical storms with their high winds and heavy rains are very hazardous and cause both loss of life and property damage. One of the largest hazards faced by Hawaiian's during storms are falling Albizia trees, an invasive species to the Hawaiian Islands known for

growing tall with brittle wood and shallow root systems (Ching et. al, 2020). In high winds these trees are very prone to dropping limbs or falling over causing large amounts of property damage and putting Hawaiians in danger. Flooding is another major problem caused by tropical storms as it can damage food and water supplies as well as infrastructure like roads and powerlines. Fast growing rural communities that have a large portion of Native Hawaiians are more vulnerable to tropical storms as lower income areas tend to have poorer quality houses, less robust infrastructure, and are generally closer to the coastal low-lying areas of Hawaii (Ching et. al, 2020).

Hawaii has implemented many strategies to reduce the effects of climate change and prepare to deal with the consequences, but they are still working to find more effective and less costly methods. Hawaii is making great strides towards reducing their dependence on fossil fuels and greenhouse gases. They are leaders in the fight against climate change and are creating a better future for their residents and the world.

Approach and Methodology

The approach to our problem began by researching how climate change specifically impacts Native Hawaiians and their culture. We conducted this research by looking at both primary and secondary sources like journal articles and government reports. The main search engine used was google scholar. Hawaii.gov was used to help find government reports on climate change issues, especially sea level rise and disaster preparedness. The main keywords used were “climate change”, “Hawaii”, “Native Hawaiians”, “coral reefs”, and “Hawaiian culture”.

The next step in our research was investigating problems caused by climate change in Hawaii. The main three issues we found were coral bleaching, sea level rise, and increasing tropical storms because they affect the social, economic, and cultural aspects of Hawaii. These are very important issues, and we wished to see how they would impact the Native Hawaiian community and what that meant for Native Hawaiian culture. First, we needed to collect background information on how climate change leads to these

issues and how the issues directly harm Native populations. Our research was conducted through primary and secondary sources such as journal articles and government reports discussing these issues. We found these sources to gain firsthand knowledge into how communities are facing climate change and how their lives are being affected.

Our final topic of research involved finding solutions for Hawaii that would prevent more damage and help the Native residents retain their homes and livelihoods. We focused on finding cost effective solutions that would not disrupt the ecosystem or environment. The best solutions we found that fit our criteria were coral gardening and shoreline hardening. We conducted this research through primary and secondary sources by finding journal articles, reports, and studies on these solutions that explained the effectiveness of each solution.

Throughout our research we found solutions that we determined were possible to implement in Hawaii. Pulling from the previous research, we brainstormed a large list of potential solutions. To determine the best solution to recommend, we organized our potential solutions into four categories: Oceanic and Coastal Adaptation, Adapting Flora, Fauna, and Culture, Disaster Preparedness, and Paris Climate Accords (Figure 3).

Oceanic and Coastal Adaptation	Adapting Flora Fauna and Culture	Disaster Preparedness	Paris Climate Accords
Reef restoration: • Coral gardening • Artificial reefs Shoreline hardening: • Natural methods like dune grass and other plants along shorelines • Artificial methods like fences and walls	• Get rid of albizia trees, prevents damage during storms • Communities work together to adapt culture to fit pressures of a changing climate • Adopt traditional farming techniques for a sustainable and adaptable food source • Save fishponds that provide many Hawaiians with food	• Education for communities on disaster awareness and preparedness • Organizations to help with disaster relief and recovery • Implement government systems and infrastructure • Create robust early warning systems	• Sign on to the Paris Climate Accords • Work to being carbon neutral as a state by 2045 • Create more renewable energy jobs

Figure 3: Collection of potential solutions that were categorized into our four main solutions.

These solutions were then judged on how they would affect the community, how effectively they solved the problem, cost effectiveness, time of implementation, and scope. We quickly determined that the Paris Climate Accords category of solutions, which involved following the terms of the Paris Climate Accords and creating more renewable energy jobs was well beyond the scope of our project because Hawaii has already signed on to the Paris Climate Accords (Yu, 2018). Thus, this was a solution we did not need to recommend.

We dug up more in-depth information on the other three solution categories and led our peers through a project seminar and used their feedback as well as our solution assessment factors to determine the final solution we would recommend (Figure 4). The two primary solutions we focused on were coral gardening and shoreline hardening which made up our Oceanic and Coastal Adaptation solution category.

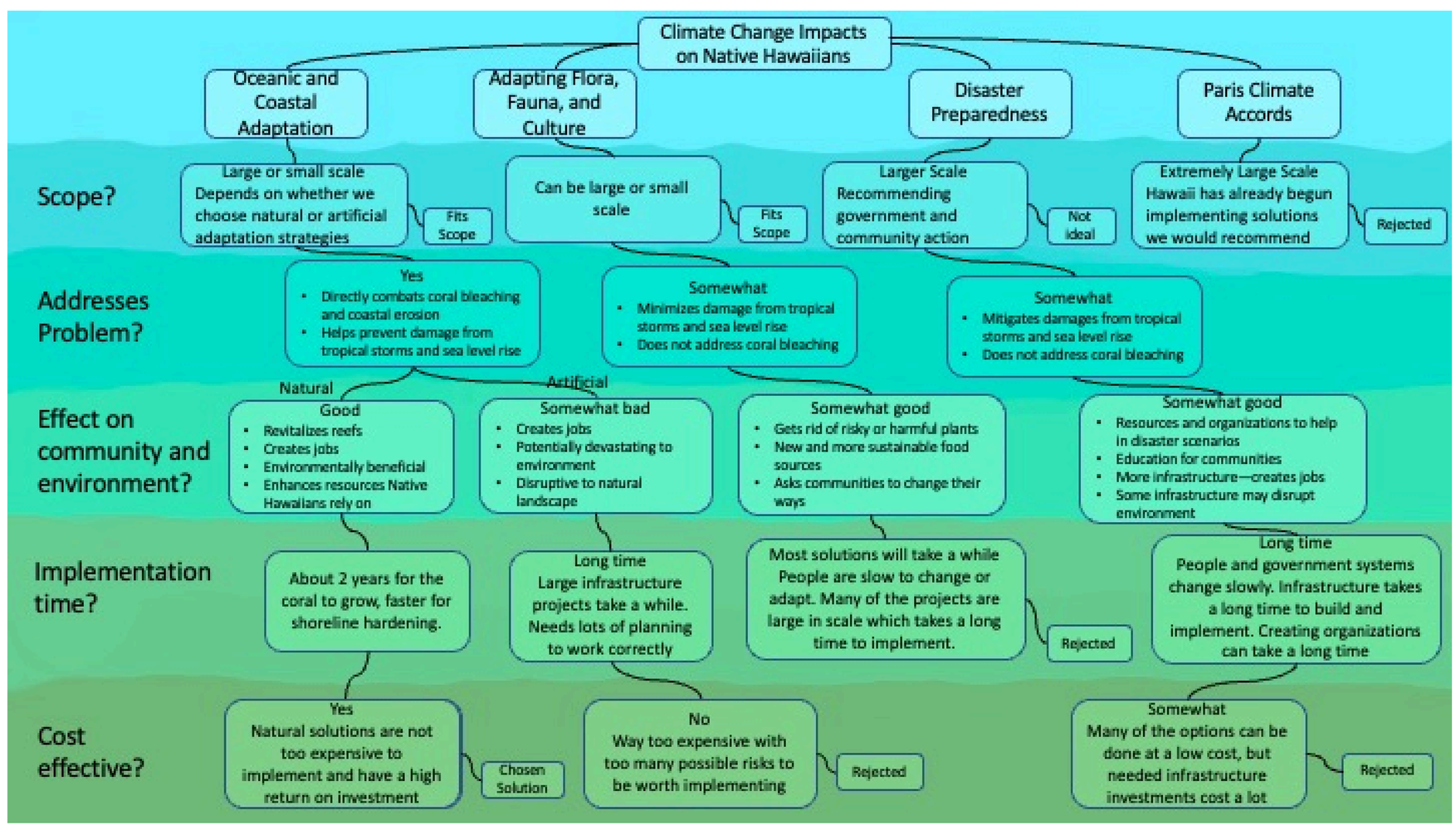

Figure 4: Decision tree that describes our decision-making process throughout this project.

Recommendations

We strive to address how climate change is affecting Native Hawaiians and recommend a viable plan to fix these issues. Through

research and analysis, we determined that Oceanic and Coastal Adaptation was the best suited solution to address the issues our project focused on. This solution combines coral gardening/ restoration and natural shoreline hardening with minimal man-made objects.

Shoreline hardening combats coastal erosion and is used in several forms on most beaches and bodies of water. Different areas require different approaches including fences, stone or concrete walls, breakwaters and sills made of granite or other stone, or even plants such as dune grass and mangroves (Gittman et al., 2016). These structures prevent sand from being swept away by waves and storm surges. Erosion is such a big issue, and shoreline hardening is necessary to protect beaches, coastal property, and infrastructure. Man-made structures for shoreline hardening can sometimes cause more harm than protection to the coastal ecosystems (Gittman et al., 2016). If a structure is not engineered perfectly, it can alter the natural flow of the waves and cause more erosion down shore. These structures do not look pleasant on beaches, deterring tourists. We recommend a “living shoreline” to be implemented on Hawaiian beaches struggling with erosion. A living shoreline uses living, native plants to “harden” the shoreline and prevent erosion. Figure 5 shows the native plants that would provide the most effective living shoreline.

Figure 5: Native Hawaiian plants to use for shoreline hardening, according to University of Hawaii Sea Grant Extension Service (2004). Top left: "Aki 'aki, ("Sporobolus virginicus" by David Eickhoff, CC BY 2.0), Right: 'Akulikuli ("Panicum fauriei var. latius" by Forest & Kim Starr, CC BY 3.0 US), Bottom left: Naupaka ("Naupaka Kahakai – scaevola sericea" by Drew Avery, CC BY 2.0)

Dune grass is effective at holding onto sand and preventing it from being washed away with its root systems (Gittman et al., 2016). There are a few species of grass native to Hawaii that can tolerate the salt water and grow enough roots to effectively prevent erosion (U. Hawai'i Sea Grant Extension Service, 2004). Plants coupled with minimal fencing can enhance the hardening effect (Figure 6). Using only plants removes the risk of harming populations of sea turtles, crustaceans, birds and can enhance their habitat (Gittman et al., 2016). Another natural form of shoreline hardening is the restoration of coral reefs. We recommend Hawaii implements a way to restore coral reefs because they serve as a natural barrier against storm surges and prevent erosion.

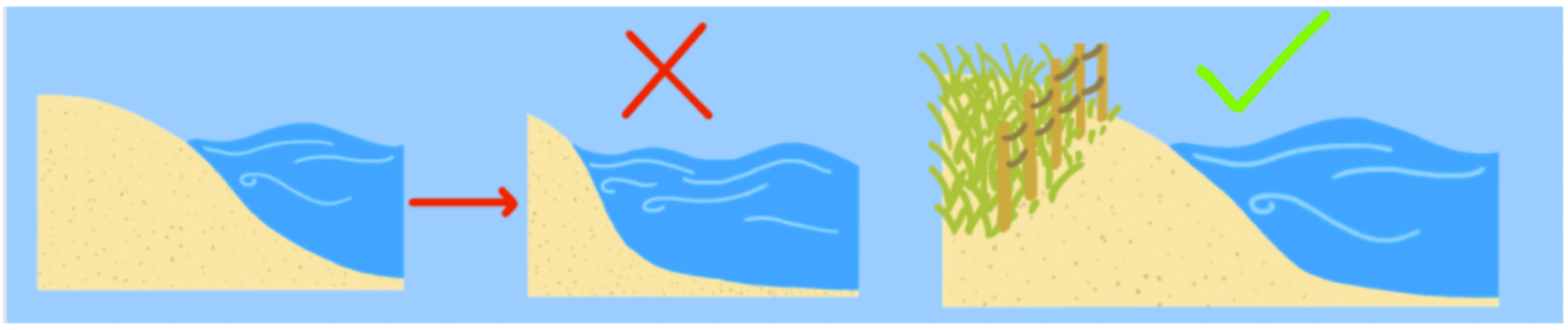

Figure 6: Graphic depicting what a living shoreline would do to help coastal erosion. Image created by Isabella Clowes.

Coral gardening is a much newer approach to coral reef restoration. In the past, damage to coral reefs were fixed with engineering projects that required lots of experts and materials. The cost of these projects was huge and altered the natural beauty of reefs via artificial concrete and limestone structures (Lirman & Schopmeyer, 2016). This type of project was not reliable to restore the dying reefs all over the world therefore more economical and efficient methods of restoration came into popularity such as coral gardening. Figure 7 shows how coral gardening collects small coral fragments from struggling reefs and moves them into a nursery to be monitored and nurtured. Within a few years, the small pieces of coral grow and can be transplanted back into the dying reef to spread.

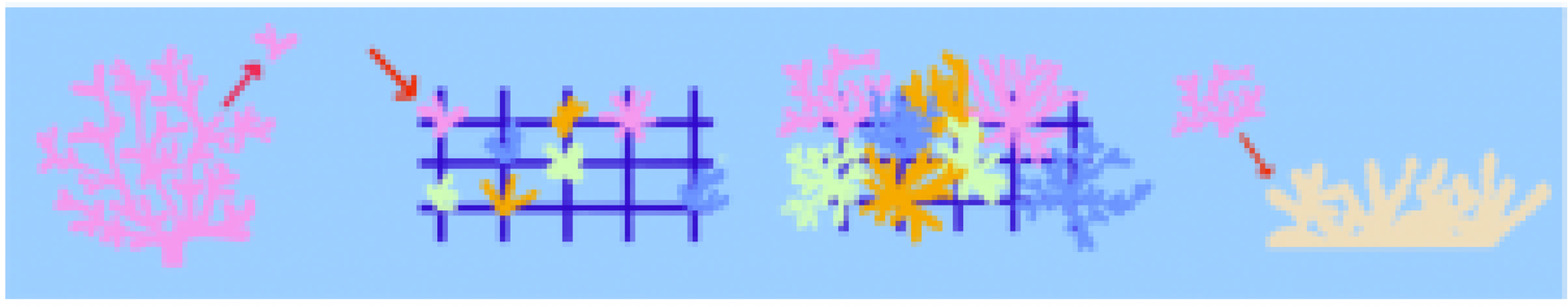

Figure 7: Graphic depicting the steps for coral gardening. Image created by Isabella Clowes

This method takes advantage of the asexual reproduction of corals, but encourages more sexual reproduction once the corals have been planted into the reef. The remaining corals living in a dying reef are too far apart to sexually reproduce. When the gaps are filled with gardened coral, they spread faster and thrive through sexual

reproduction (Lirman & Schopmeyer, 2016). Coral gardening helps bleached reefs provide for organisms as a lively ecosystem once again. Reefs are a hot spot for marine activity and serve as a habitat for fish and invertebrate species by providing protection and food. The restoration of reefs in Hawaii would boost fish populations which Native Hawaiians rely on for food and income. Hawaii's tourism industry depends on coral reefs, with reef activities bringing in about $304 million annually for the state (NOAA, 2020). Coral gardening is the best method to restore reefs while retaining their beauty and attraction by not adding man-made materials.

Implementation

Oceanic and Coastal Adaptation requires many elements to be implemented. Figure 8 describes the order in which to have successful implementation of coral gardening. Since coral reefs are important to tourism, it would make sense to get companies in the tourism industry involved in reef restoration. Major tourist hotels on the coast or scuba diving services could fund coral gardening and hire Native Hawaiians to perform the work. The indigenous people have more knowledge about the environment and corals than the average citizen and they are very invested in their local environments. These companies would profit off the restoration of reefs by attracting more tourists and could even find volunteers to do the work. To start the gardening process, areas with living corals need to be mapped and identified before collection. An area in the ocean to place the nursery with the best light and temperature needs to be selected. Figure 8 shows the indirect benefits coral gardening will have for the Native Hawaiian population.

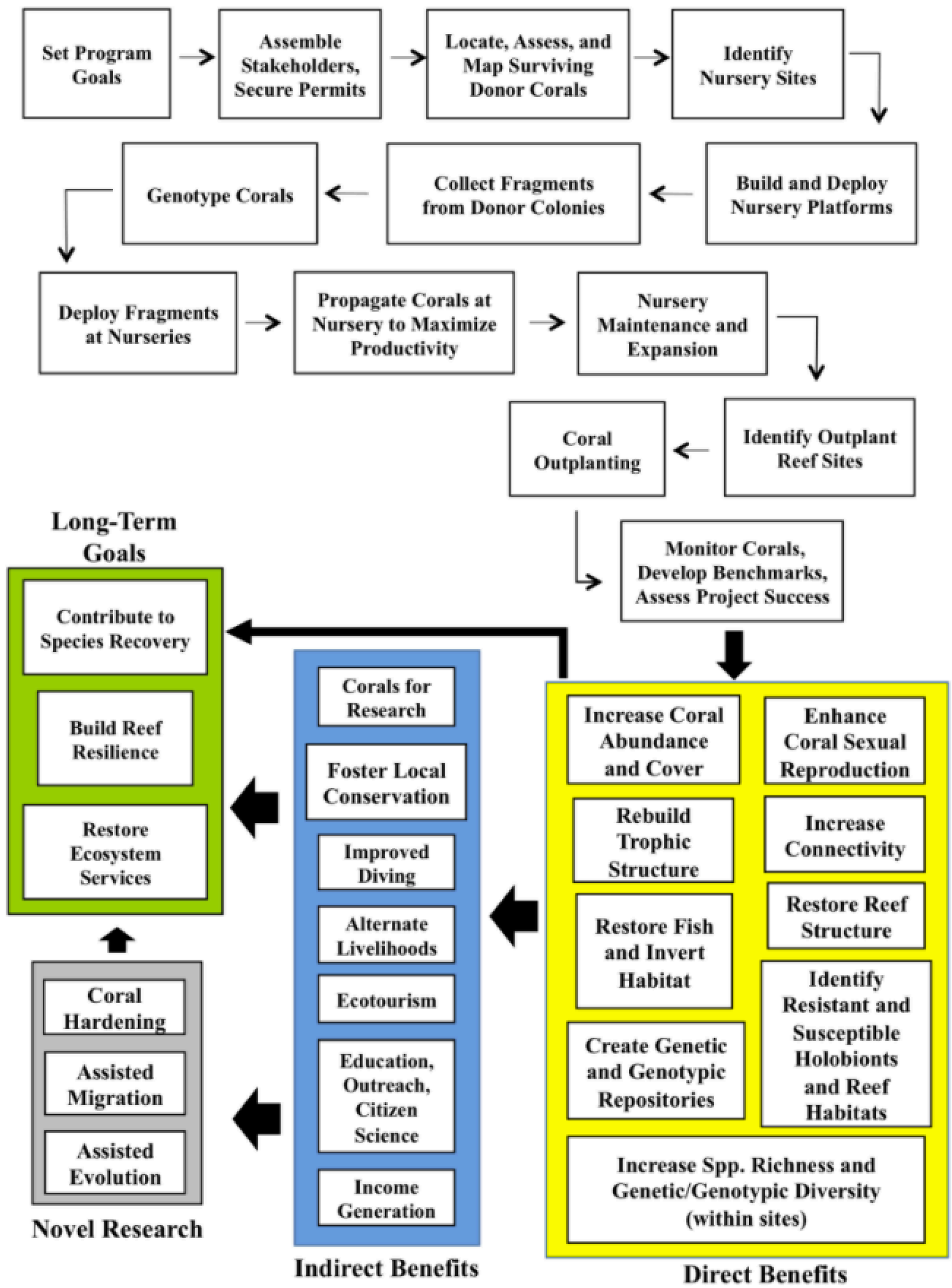

Figure 8: A successful plan of implementation the government or private companies can take with indirect/direct benefits and long-term goals of coral gardening and restoration for Hawaii ("Coral gardening conceptual framework" by Lirman & Schopmeyer, 2016, CC BY 4.0).

For our plan to be implemented there would need to be an advisor to oversee the implementation and agree to the plan. Organizations,

groups, and people in Hawaii who are focused on helping solve the issues of climate change would be great partners and possible stakeholders such as the Nature Conservancy, Hawaii Conservation Alliance, and Sunrise Movement. Preferably, a person of Native Hawaiian descent who is active in the Native Hawaiian community could oversee the project in order to unite these solutions with Native Hawaiian knowledge and empower the Native community. To start gardening, workers would have to be trained by an expert in corals to identify, collect, nurture, and transplant the coral. Once they are trained, the process of gardening should be relatively simple. The government could create a committee based on oceanic and coastal adaptation that focuses on successfully implementing solutions. Having government support could create many jobs for Native Hawaiians and they could share their knowledge of the land with the committee. This is not a short-term solution because the coral needs at least two years to fully grow before transplantation, but the possibility of seeing great changes in just two years creates hope for this solution. Shoreline hardening implementation is easier because it does not require constant maintenance as coral gardening does. An appropriate species of plant needs to be picked out that specifically meets the needs of the area and will be able to thrive under the specific conditions. Depending on the vegetation style chosen, the living shoreline may require additional pruning and landscaping throughout the year compared to other choices (U Hawai'i Sea Grant extension Service, 2004). A living shoreline project requires initial funds to purchase the plants and fencing but they are relatively low-cost. The government or private companies would need to provide wages to workers who plant and prune the living shoreline all across the Hawaiian coast.

Shoreline hardening's success won't be immediately visible since its goal is to prevent further erosion from taking place (Figure 9). Preventive solutions are difficult to judge because it is unknown if the solution has been beneficial or if it was just as effective as doing nothing at all. If shoreline hardening prevents major coastal erosion, this would be a success. To determine the success of hardening

measures, it would take multiple years to measure the coastal changes year after year. Little or no change in the coast demonstrates successful results of shoreline hardening. The effectiveness of coral gardening is much easier to judge because, while it is a long-term solution, the final goal would be to restore Hawaii's coral reefs to a point where they are able to thrive on their own despite the effects of climate change. The way to demonstrate success of this solution is to assess the health of Hawaii's reefs after the gardening projects have begun. Oceanic and Coastal Adaptation is a solution that will take time to implement effectively, and it may be difficult to judge the success of such a long-term solution.

Figure 9: Image of what a "living" shoreline is and what we expect Hawaii's coastline to be when the solution is implemented. "Beach Dune on Pea Island NWR" by Cindy Heffley, USFWS, Public Domain.

Conclusion and Broader Impacts

Coral gardening and shoreline hardening would utilize the natural resources to revitalize the environment that supports Natives

Hawaiians. Natural resources such as fish and plants can prosper again, giving Native Hawaiians a source of income and livelihoods for their families. Coral reefs would be biodiverse again, serving as a hotspot for marine creatures. Beach erosion would not be a problem because of the natural barriers and Hawaii can adapt for the future. Tourism would continue as a booming industry giving Hawaii more abilities to become carbon neutral and keep their environment stable.

See Appendix 2 for the infographic used by the team on Project Presentation Day.

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15. Destigmatizing Nuclear Energy to Decarbonize the Worlds' Power Supply

By Keelan Boyle, Frank Ford, and Daniel Shea

Abstract: Nuclear energy carries a stigma in the minds of many. But why? Stigmas toward nuclear energy have existed since World War II and have only been solidified by accidents. However, the risk of these events occurring is decreasing through the implementation of numerous safety measures. This includes nuclear waste being disposed of properly, better training, more innovative nuclear reactors and a more thorough understanding of nuclear power. How are stigmas affecting the expansion of nuclear energy, and how can we show the public that nuclear energy is the most efficient source of renewable energy?

Introduction:

It's early in the morning of March 28th, 1979. Alarms are blaring on Three Mile Island in Pennsylvania, indicating that something went wrong in one of the nuclear reactors. Reactor one had begun normal maintenance work which led to the second of the three reactors to run at higher-than-normal capacity. A blockage in the water

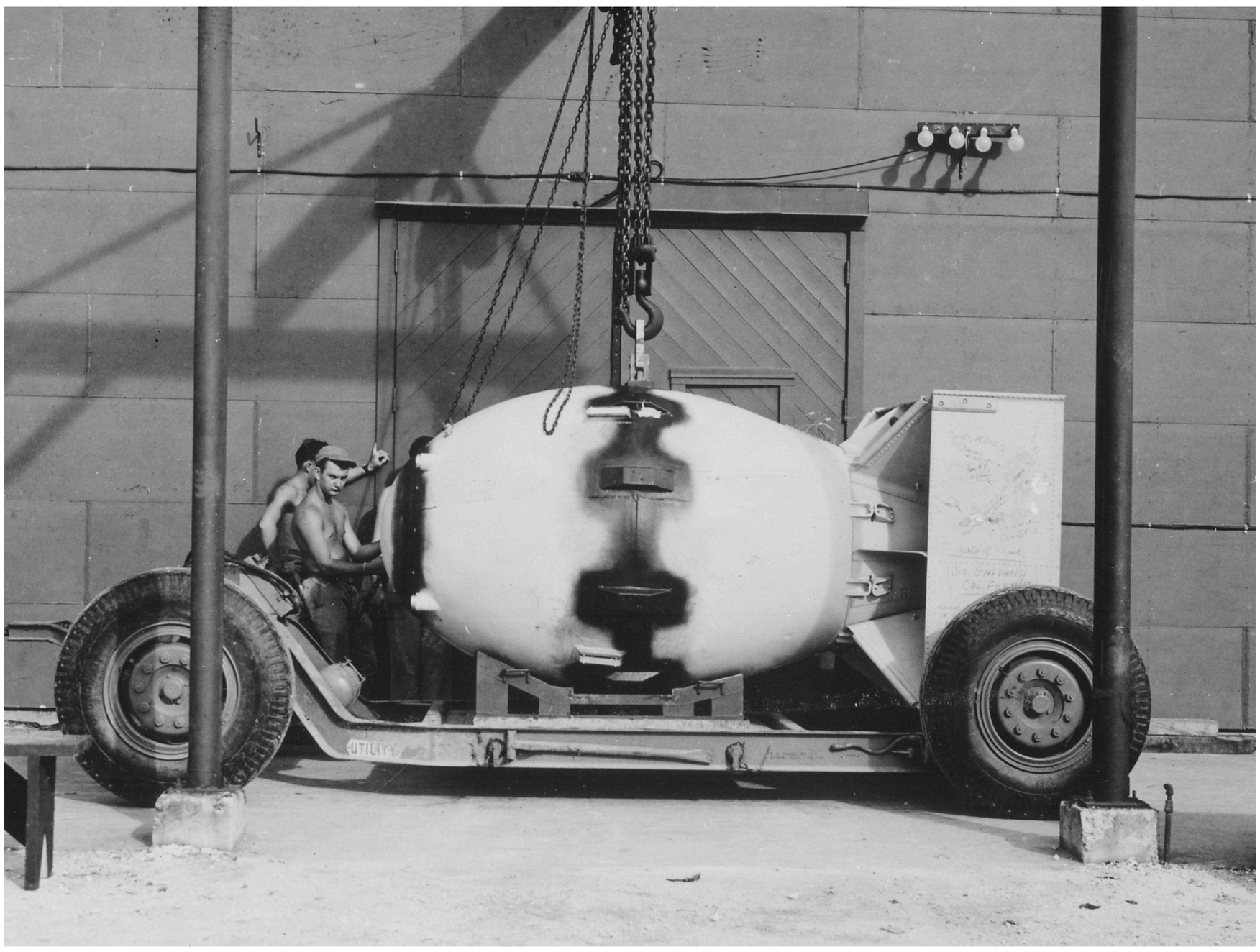
filtration system was unable to be cleared and led to an influx of a water/steam bubble mixture into the reactor (NRC, 2018). High pressure triggered a relief valve on top to open to relieve pressure. This valve should normalize the pressure in less than 20 seconds, however, it remained open for 142 minutes and the operators failed to notice due to a faulty indicator that had implied the relief valve had closed (Murray, 2014).

Figure 1. An image of Three Mile Island located just south of Harrisburg, Pennsylvania. "Three Mile Island nuclear generating system" by Z22, CC BY-SA 3.0

This caused radioactive water to the containment floor and radioactive gases out into the world through ventilation systems. This release, however, was so miniscule that those within a 50-mile radius, if exposed over a lifetime only one additional cancer death would occur. This proved to be a perfect example of the importance of quality operator training and design efficiency (Murray, 2014). Several well-known disasters at nuclear energy plants have left a stain on the public's view of nuclear energy and while nuclear

energy has some dangerous negative effects, the benefits of this form of safe and clean sustainable energy outweigh the costs.

One of the main issues with nuclear energy is that the history of nuclear power is almost all negative. The process used to create clean energy was once originally used for the sole purpose of destroying. Nuclear power conjures up images of World War II and the race to create the atomic bomb, a bomb with greater power and more devastating consequences than anything the world had previously seen.



This image was taken of the first atomic bomb. Created through the Manhattan Project this bomb was the beginning of the end of the second World War. "77-BT-187: Tinian Island, August 1945", National Archives, Public Domain.

`The history behind this form of power is riddled with death, destruction, and lasting consequences, however, the discovery of clean energy from nuclear power could have changed public perception. Due to a few accidents the public opinion of this form

of clean energy was changed for decades. Chernobyl, Three Mile Island and Fukushima Daiichi are the three main disasters that led to such a negative view of nuclear energy. With time, advancements in safety and a new type of generation, nuclear energy has started to come back into positive light. A new understanding of nuclear energy has led to a push for the reinstatement of many nuclear plants that should be considered with great interest by governments and the public once again.

This project was intended to address the negative stigmas associated with nuclear energy. In the beginning, this group viewed nuclear energy as a somewhat dangerous and mysterious form of clean energy. Opinions shaped by past disasters and a more recent devastating disaster in Fukushima, Japan led to discussion on nuclear power. From this stemmed curiosity about if these views were justified or if this form of sustainable energy was rather one of the most promising electricity producing technologies we have on Earth. Questioning preconceived notions led to a new understanding of the topic, a topic which has the potential to fight climate change by reducing carbon emissions. The hope of this project is to educate the masses on how the expansion of nuclear power, if done correctly, would have benefits that greatly outweigh the risks.

The History of Nuclear Power:

During the cold war there was a nuclear arms race between the United States and the USSR. One of the largest breakthroughs at that time was the discovery of the process known as fission. Fission made it possible to forcibly split an Urianum-235 atom by firing a neutron at the atom (as seen in figure 3). This process released a large amount of energy which made it possible to make bigger

and more destructive bombs. This led to the field of nuclear science (Gale, 2020).

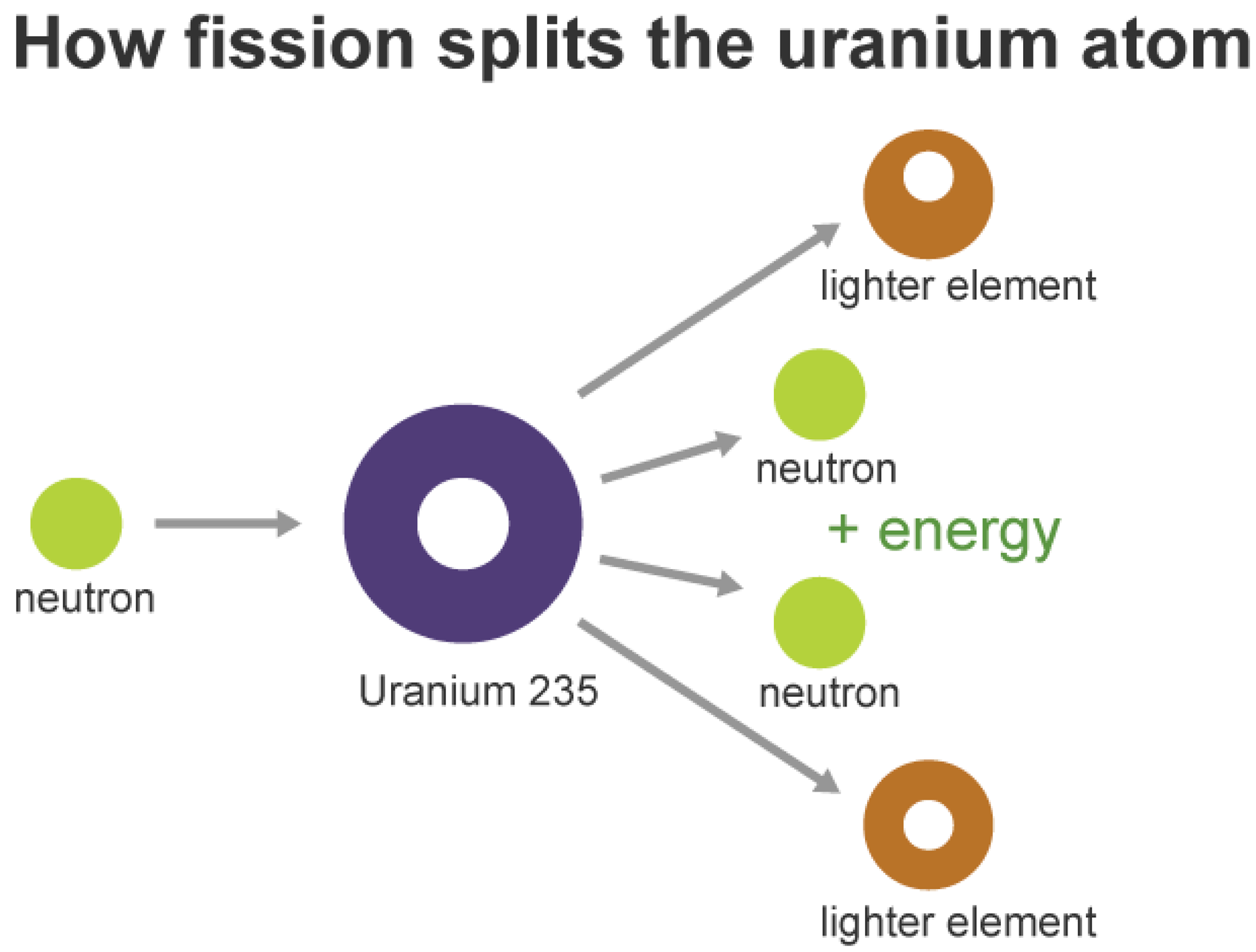


Figure 3. The Process of fission. This drawing shows the process of fission. It visually shows how a neutron splits a Uranium 235 atom thus releasing energy and creating four byproducts. "How fission splits the uranium atom", National Energy Education Development Project, Public Domain.

While many during this time concentrated their efforts on creating destructive devices some became interested in turning the destructive power of fission into electricity. This led to the construction of the first nuclear reactors but this new technology, however potential, it was linked to destruction and war in the mind of the public. This made implementing this potentially dangerous technology exceedingly difficult, but with educating the public through a variety of means the public grew to understand and accept nuclear energy (Dewan, 2019). This changed with the failures of two notable reactors: Chernobyl and Fukushima Daiichi (Chater, 2005). Even though these tragedies were significant in the evolution

of nuclear power, there was a remarkably low loss of life associated with a nuclear reactor meltdown (UNSCEAR, 2008). The stigmas originating during the second world war were once revitalized as the world witnessed the risks associated with nuclear power. One may wonder though, if the influence of the atomic bomb and nuclear power plant failures are the only causes of negative stigmas against nuclear power. It has been found, however that many other factors influence people's opinion on the topic at hand.

Several of the main stigmas of nuclear energy come from governmental concerns. Those who hold a distrust in their country's government or society tend to lean away from the idea of nuclear energy, especially if the government is promoting the idea. One example of this is in South Korea, which, statistically, has lowest overall level of social trust, which is defined as the belief that others in a society can be trusted (Kim, 2018). South Korean citizens particularly dislike how the nuclear power program has been a national organization since the 1970s. As a result, they have a particular distaste in nuclear energy options, since installing nuclear power plants is already a risky proposition. Despite this, the country uses nuclear power to generate 26.9% of South Korea's electricity as of 2017 (Kim, 2018).

Environmental concerns additionally play a role, as studies have shown that individuals with biospheric values, that is, they value the environment, tend to disagree with the idea of using nuclear energy, since their risk perception of the matter is higher (De Groot, 2013). In the minds of people who hold these values, the number of radioactive accidents that have occurred in the past few decades overshadows the fact that nuclear energy has no carbon emissions and uses land more efficiently than other types of renewable energy.

Finally, peoples' life experiences, as well as their values, play a huge role in forming their opinions about nuclear energy. Jim De Groot studied three major life values when evaluating peoples' perceived

risks, benefits, and acceptability of nuclear energy: egoistical, altruistic, and biospheric. Egoistical people, like nuclear energy, obtain a general dislike from members of society. Egoistical people tend to put their own needs first rather than thinking about others, and they tend to be self-centered. These types of people have a high benefit perception of nuclear energy, meaning they see more benefits involved than risks. On the contrary, altruistic people strive to bring advantages for others, even if they get hurt from the results. These types of people are very selfless. Finally, biospheric people are those whose main values center around the environment and preserving mother nature (Wang, 2021). Both altruistic and biospheric people have an elevated risk perception of nuclear energy, believing that it includes more risks than benefits (De Groot, 2013). Demographic statistics, such as gender, income, and education, as well as benefit perception, and trust, affects peoples' views on nuclear energy, with men, those with higher education, and those with lower income having a higher benefit perception towards nuclear energy.

Positives

Over the past 30 years, nuclear energy has demonstrated the ability to produce electricity at a low, predictable, and stable cost due to its low dependence on the price of uranium. Furthermore, uranium is a widely distributed natural resource that many countries have access to. Consequently, it would be unlikely that uranium mining would lead to the international tensions we see today for oil or gas (Poinssot et al., 2014). The effect that nuclear energy could potentially have on developed countries foreign policy, specifically the United States, may be immense. The need to rely on unstable countries for oil has led in part to many recent conflicts and if those could be avoided it would benefit both the dependent and independent.

While uranium is widespread throughout the known world, the overall supply of the resource is anticipated to last only a few decades if current nuclear waste or spent fuel storage methods are continued. The ability to use spent fuel for secondary purposes through recycling would allow for nuclear energy to become the world's main energy source (Hannum & Stanford, 2005). The recycling of spent fuel is not too far in the future, however, as France has already began doing so. They have standardized their nuclear reactors designs into three simple types: the three-loop 900 MWe (34 reactors), four-loop 1300 MWe (20 reactors) and four-loop 1450 MWe (4 reactors). By doing this they can more efficiently manage spent fuel (Krikorian, 2019). They manage this fuel through recycling, the process of recycling spent fuel lies in converting plutonium, a byproduct of fission in nuclear power plants, and uranium into a mixed oxide. This oxide can then be used again in nuclear power plants as fuel. This recycling has allowed France to reuse about 23,000 tons of fuel. This amount of fuel has been able to power them for an additional 14 years (Krikorian, 2019). France has shown the enormous benefits of reusing spent fuel, not only for limiting high level nuclear waste, but also limiting its natural uranium usage and thus promoting France's energy independence.

Although France is a prime example of what other countries should begin to do, right here in the United States a new generation reactor and process would allow for nuclear energy to be more efficient. A safer and more sustainable nuclear energy cycle has been designed to be more efficient and effective. This design would use faster moving neutron atoms. This process allows for all the uranium atoms to be dissolved and converted to energy therefore eliminating much of the spent fuel produced today (Hannum et al., 2005). Additionally, this type of new generation reactor would be able to consume recycled fuel produced in slower moving, older generation, thermal neutron reactors. This potential technology would finally reduce long lived waste by producing waste that has a radioactive half-life of only about a hundred years (compared

to thousands of years). This process could support nuclear energy generation indefinitely (Hannum et al., 2005). This would allow for the most efficient and effective use of Earth's available uranium resources.

Another promising technology of nuclear energy is the process of fusion to create energy. Fusion is the process of combining deuterium and tertium (isotopes of Helium) to form hydrogen. This happens only when the D-T (tertium-deuterium) mixture is heated to extreme temperatures, upwards of 100 million degrees Celsius. Once heated to this temperature the two isotopes of Helium create a plasma, the fourth state of matter, which is simply a hot electrically charged gas. Once in this state, the environmental conditions necessary to overcome the electrostatic repulsion are satisfied and a strong nuclear force binds the nucleons together in the nucleus, thus starting a quantum mechanical tunneling process and forming hydrogen (see figure 4) (Kikuchi et al., 2012). The resulting hydrogen is lighter than the D-T mixture resulting in a release of heat energy, which is then used to heat water to make steam, turn a turbine and finally generate electricity. This process has been demonstrated in small reactors around the world but has been proven inefficient at a small scale.

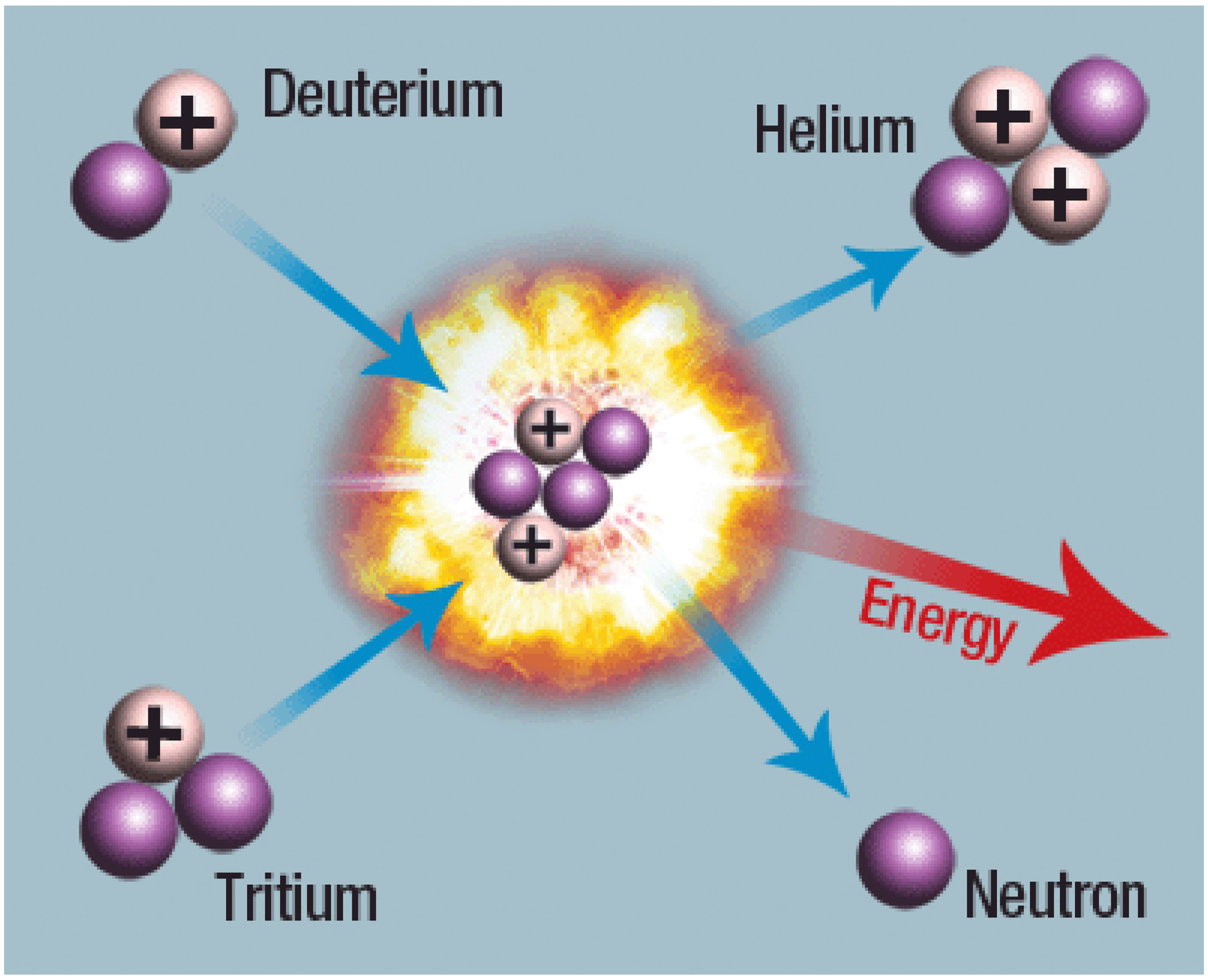


Figure 4. The process of fusion. This drawing shows the atoms necessary for fusion and the products created in this reaction, including the release of heat energy. "Nuclear fusion", CC BY-SA 3.0

This discovery led to international agreements that a large fusion reactor must be built collaboratively. The International Thermonuclear Experimental Reactor (ITER) agreement was signed on November 21st, 2006. It was a formal agreement that committed China, the European Union, India, Japan, Korea, Russia and the United States to building the world's first effective nuclear fusion power plant. The ITER organization was officially established on October 24th, 2007 after the ITER agreement was ratified in each participating country (Ikeda, 2009). This massive plant located in Southern France will be the first efficient nuclear fusion power plant. The predictions of the energy output of ITER is 500 MW of thermal power for 400-600 second periods for the 50 MW of input energy. This is a tenfold return compared to the current record

output of 0.67% held by the JET tokamak in England (Dhar, 2020). ITER is currently 72.1% complete and is anticipated to be finished by 2025. At this time plasma will begin to be created and by 2035 the plant will begin efficiently producing energy (Dhar, 2020).

Figure 5. This image shows the almost complete ITER plant located in Southern France. It will be the largest plant related to nuclear energy and the first efficient nuclear fusion power plant. Oak Ridge National Laboratory, "ITER Site", by oakridgelabnews, CC BY 2.0

Once completed, this power plant will not only be efficient it will also produce significantly less waste and this waste will have a short half-life, making it less dangerous than traditional nuclear waste. Additionally, the ITER plant will have no risk of a nuclear meltdown contrary to current fission reactors (Ikeda, 2009). Finally, similarly to nuclear fission plants, ITER and all future fusion plants will release zero carbon emissions making it more ecofriendly than other renewable energy.

To further prove the point that nuclear energy is more ecofriendly than renewable energy, a case study was examined. In the case

study, done from 1984-2007, 19 high income countries were analyzed, and it was determined that in the short run, at least, nuclear energy usage contributes less greenhouse gas emissions (GHGE) than renewable energy. It was found that the worldwide operation of nuclear power plants currently saves about 10% of CO_2 emissions from world energy use (Apergis et al., 2010). This reduction in emissions would only increase as the number of nuclear plants in the world grew. In addition to the current reduction, data from this study determined that without nuclear power plants carbon emissions would have been about a third higher, making the world that much closer to a tipping point in global warming (Apergis et al., 2010). The benefits of nuclear energy when simply compared to renewable point to the fact that society should reconsider nuclear energy as a clean and safe form of sustainable energy.

Challenges

While the potential upsides of nuclear reactors are potent so are their drawbacks. The largest of which is the potential for a nuclear disaster. With this comes huge costs that come in the form of money, environmental damage, and human life. However, all these negatives have caveats. As nuclear energy grows in popularity the science behind them shows the true cost of a reactor, and the costs may be surprising. Nuclear energy has the least deaths per billion kWh (kilowatt-hour) of any energy supply. As of 2014, nuclear energy kills one person for every 25 billion kW/h, compared with coal that results in 100 deaths every billion kWh (Figure 6, Brook, 2014). This statistic is incredible considering that it includes the energy production, fuel extraction, and accidents that may occur of the given power source. Additionally, the total amount of deaths will continue decreasing with the implementation of newer, safer reactors.

Mortality rates for each energy source in deaths per billion kWh produced.
Source: Updated (corrected) data from: World Health Organization; CDC; Seth Godin; John Konrad.

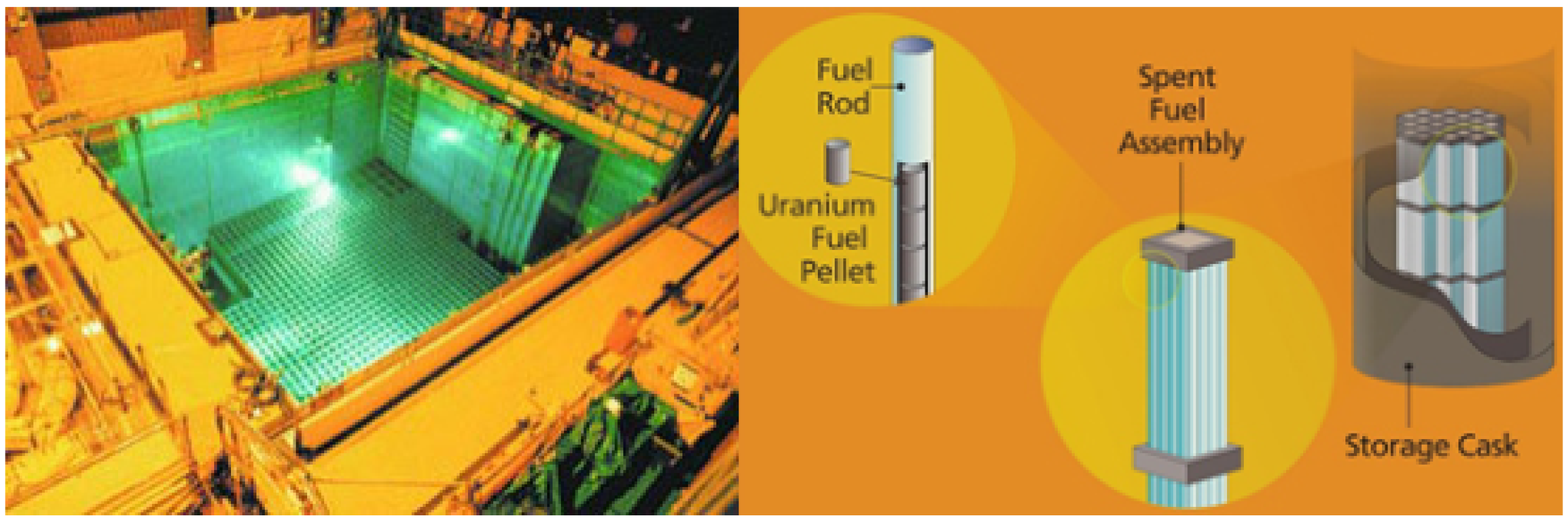
Energy source	Mortality rate (deaths per billion kWh)
Coal — global average	100 (50% of global electricity)
Coal — China	160 (75% of China's electricity)
Coal — U.S.	15 (44% of U.S. electricity)
Oil	36 (36% of global energy, 8% of global electricity, none in U.S.)
Natural gas	4 (20% of global electricity)
Biofuel/biomass	24 (21% of global energy)
Solar (rooftop)	0.44 (<1% of global electricity)
Wind	0.15 (~1% of global electricity)
Hydro — global average	1.4 (15% of global electricity, 171,000 Banqiao dead)
Nuclear — global average	0.04 (17% of global electricity, with Chernobyl & Fukushima — none in US)

Figure 6. A comparison of energy sources- number of deaths per billion kilowatt hours of electricity produced. "Mortality rates for each energy source in deaths per billion kWh produced." Brook et al., 2014. CC BY-NC-ND 3.0

Another concern related to health, is what are the environmental concerns with radiation? This means that coal power plants emit more radioactive particles into the air than nuclear reactors since coal generators let mercury and other heavy metals into the air (Brook et al., 2014). When a reactor does have a serious malfunction a significant amount of radiation could be released. The two plants that have emitted the most radiation was Chernobyl and Fukushima. At Chernobyl, most of the radioactive particles were Iodine 131 and Cesium 137 (Brook et al., 2014). These two particles have a half-life of eight days and 30 years, respectfully. This is significant since the time of contamination of the immediate area will be significantly less potent in just a few months with most of the radioactive-iodine decays. The cesium will stay around for a long period of time, around 120 years. During this time, however, the radius of contamination will slowly shrink since as the distance from the reactor increases the amount of radiation decreases. This is a serious problem that can be remedied by different types of reactors, and more safety features. This includes making reactors that use

less potent fuel, having reactors that do not create a positive feedback loop (in the case of Chernobyl) and thoroughly checking equipment.

The next major concern that people have is where will nuclear waste go? Currently the United States government is asking a similar question. This is because there are a few potential spots to store this waste (Nevada and Texas), but no official plan on where to store it. In the meantime, nuclear power plants have safe ways to store spent fuel within the power plant. There are two main ways: fuel pools and dry storage. Fuel pools are exactly as they sound. The spent fuel is put into containers and put at the bottom of a large pool filled with water as pictured in Figure 7 (K. Holt, personal communication Feb 19, 2021). Placing these containers in the pool allows anyone to walk right up to the water's edge and experience no extra radiation (K. Holt, personal communication Febuary 19, 2021). This is because water is a great substance to absorb radiation. The other way to store spent fuel is with dry cast storage as shown in Figure 8. This storage technique involves creating a large storehouse out of concrete where the fuel is put in canisters and given a large amount of air flow to keep cool. With this contraption, a person can stand right next to the concrete and experience no extra radiation.



Figures 7 and 8. Dry fuel pool and dry cask storage. Pictured on the left is an image of a nuclear waste or spent fuel pool. Spent fuel is placed in these pools in containers in order to contain the radiation and cool the extremely hot waste. On the right is a drawing of a spent fuel rod which then is placed in an assembly and then finally moved into a storage cask. "Spent Fuel Pool at the San Onofre Nuclear Generating Station" and "Dry Storage", National Regulatory Commission. CC BY 2.0

Even though there is not a good place to permanently store nuclear waste, it does not mean that there is no use for it. One of the biggest uses of this highly energized spent fuel is to power different reactors. This does not get rid of the nuclear waste completely, but it does decrease the energy in it. This is significant because with less energy in the waste it is less dangerous to humans and our surroundings while also decaying faster (compared to plutonium). There is another use for both types of waste as well: in medicine. Nuclear waste's primary usage in medicine is to be injected into the body to kill specific cells.

The last major downside of nuclear power is the cost to build a reactor. This is because it takes around 14 billion USD and seven to ten years to build a new nuclear reactor (World-nuclear, 2020). This is due to each reactor being so complex, custom built in each location, and there is not always support for nuclear energy in the government or people. All these things make it difficult for a power plant to be built. This does not include the millions of dollars that are needed to shut down a reactor when the time comes. Some ways that this difficulty could be diminished in the next few years, is the creation of modular nuclear reactors. These reactors are small and can be produced in a factory making them cheaper to own and operate.

Why Education?

Studies have shown that the most effective way to reduce nuclear energy stigma is to educate the young public about its benefits, as well as its challenges (Yim, 2003). Our group has deducted that the most reasonable approach is to present our findings on the benefits and challenges of nuclear energy to children attending high school. We have reached out to the Science & Engineering Curriculum Liaison for Worcester Public Schools to request a presentation to

the high school students of Worcester public high schools. We have arranged a meeting with them. If approved, we will give a presentation to the high school students of Worcester about the benefits and challenges of nuclear energy, as well as what they can do to reduce its stigmas. We will present the information found through research as well as the safety measures that are being implemented towards nuclear energy.

Children in the high school age range are the ideal group to educate on the benefits and drawbacks of nuclear energy for a multitude of reasons. Studies have proved that the human brain does not stop developing until the person is in their mid-20's (Pujol et al., 1993). Since high school students' brains are still developing, they will absorb information the easiest. High school students also have a multitude of knowledge to gain, so they are in the age of curiosity, where they yearn to learn the most about the outside world as they can. Due to this lack of knowledge, their political attitudes have not yet fully developed, so they will view the presentation and analyze it with views less fixed and more open to being changed. The education system does not mention the benefits of nuclear energy, as this contradicts its teachings about World War II and the disasters that have brought upon severe drawbacks to nuclear energy. However, this system is the largest reason why stigmas spread quickly, and as a result, benefit perception towards nuclear energy is getting more increasingly rare. Learning about the benefits of nuclear energy, as well as how its drawbacks can be improved, will give the students a new view on nuclear energy, and make them aware of the unconscious negative bias others hold on the matter. The most important reason why educating the younger public on nuclear energy is so important is because this is the current age of the pioneers of the future. Presenting the drawbacks to nuclear energy is important in the sense that these future pioneers require knowledge of a problem in order to improve it. However, a pioneer will not be motivated to fix this problem unless

they see a long-term benefit, and the long-term benefit is the focus of our presentation.

Our focus is on education after studying the effect of nuclear energy education in France. France has the largest percentage of electricity powered by nuclear energy, at 80% (Lee & Gloaguen, 2015). This is due to France's educational system, which demonstrates pro-nuclear energy teachings. This means that most of the French public obtains a positive bias towards nuclear energy, and they even believe that France handles nuclear energy better and more efficiently than other countries (Lee & Gloaguen, 2015). Studies have also found that the average French citizen holds more knowledge on the history of nuclear energy in their country, than citizens of other countries on their own respective histories (Lee & Gloaguen, 2015) This insight has led to very little political debate over the validity of nuclear energy, as well as on catastrophic nuclear events, such as Fukushima. These incidents have had little effect on France's use of nuclear energy. Conversely, the United States' education system is the opposite, with most US citizens perceiving nuclear energy with a negative lens. If the general United States public learned more about the benefits of nuclear energy, the results could lead to numerous pioneering feats, such as the expansion of nuclear energy, financial support for nuclear energy research and a more effective waste storage and/or usage plan.

Recommendations:

To move forward on destigmatizing nuclear energy, we are going out into the world and teaching the importance that nuclear energy has and will have on the power sector, and the health of our world. If you want to get involved with this campaign here are a few things that you can do. First, research what nuclear energy is and its history and current advances (the reference section is a great place

to start). This will both further our goal in educating you about nuclear energy while also allowing you to share your newfound knowledge with the world. Another way to get involved is to join the nuclear movement. Join a pro-nuclear organization, contact a local statesperson, and or attend rallies. This will show our government that we want what is right and healthy for our planet and ourselves. These are two ways to get involved but most importantly keep the conversation going, talk to people about nuclear energy, get them thinking, because once someone is comfortable with an idea it is much easier to convince them that it is good.

See Appendix 3 for the infographic used by the team on Project Presentation Day.

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16. Small Scale Carbon Capture Implementation and Utilization

By Gabriel Espinosa, Jack Hanlon, and Alexander Wadsworth

Abstract: Humanity needs to rethink its approach to the development of renewable energy. With a global economy still driven by the combustion of fossil fuels, carbon capture technologies present a viable means of transitioning to clean energy. The ability to harness energy emissions for utilization and storage will allow both developed and developing countries to minimize their carbon footprint without stunting their economic growth. These technologies must be used in tandem with ecological fuel sources to escape the self-imposed carbon lock-in. What does the implementation of carbon capture look like on the campus of Worcester Polytechnic Institute and how can carbon dioxide be utilized to benefit the local community?

Figure 1: A photograph of the WPI campus with the powerhouse smokestack centered in frame, The depicted smokestack releases nearly 8,000 tons of carbon dioxide every year, roughly equivalent in weight to 43 Blue Whales.

Introduction

How do we end a relationship centuries in the making? As much as we would love to be hopeful of our current climate change situation and the potential to go green in the near future, we must first face the reality of our fossil fuel based global economy. Humanity has built a world which revolves around the extraction and combustion

of exhaustible fuel sources and cutting the cord, without facing the reality of our path dependence, will be catastrophic.

Although the reality of carbon lock-in, the fossil fuel-based systems path-dependent process driven by technological and institutional increasing returns to scale, paints our prolonged relationship with carbon-based energy as inevitable (Unruh, 2000). A path forward can be found with carbon capture, the ability to harness energy emissions for utilization and storage. The various technologies discussed in this paper will help to establish a transition period, allowing countries to cut back on emissions while they upgrade their energy infrastructure to renewable sources. In conjunction, a host of applications look to challenge carbon dioxide's place in our world, bringing new modes of sequestration and reuse of destructive greenhouse gasses. As we will be discussing the feasibility of these technologies on a small scale, we decided to limit our scope of research to one specific region, as we believed this would give the best estimation of implementation and have the possibility of scaling upward. Explicitly, we will focus on the use, implementation, and application on the campus of Worcester Polytechnic Institute in Massachusetts, as they have great potential for these technologies.

Background

Carbon fuel sources were untouched by humanity up until the eighteenth century and stayed a rare commodity until the Industrial Revolution took off in the nineteenth century, once machines such as the steam engine, electric motor, and light bulb were invented. In a matter of nearly two hundred and fifty years, both the demand, production, and use of coal has increased more than two thousand-fold (Hone, 2020; Ritchie & Roser, 2017). This rapid buildup restricted flexibility among competing companies within each industry, leading all who wanted to grow throughout the economic

boom straight to coal, an action which has kept all industry leaders stuck with coal to this day. As the excessive burning of fossil fuels continues, humanity has been forced into a challenging predicament: discovering a method to escape the carbon lock-in by any means possible.

Carbon lock-in is viewed as a mix of systematic forces put in place by preexisting industry that elevate fossil-based fuel sources over natural and renewable sources, despite the numerous advantages found within those other sources (Unruh, 2000). Many of the preexisting industries that managed to grow on account of these carbon filled sources continue to release exorbitant amounts of emissions, with successful attempts to bring green energy lacking. Two of the largest emissions contributors, the electricity generation and transportation industry, struggle to properly integrate these advantageous fuel sources due to an exponentially increasing demand placed upon them both (Unruh, 2000). The two come together to emit nearly 30% of all greenhouse gasses globally and in fully developed regions these levels have reached 50% of all gas output (EPA, 2020). Not all blame can be placed on current day industry though, as their infrastructure had previously been laid out for them and societies increasing demand and wealth only forces their hand toward carbon based pre-established methods (Seto et al., 2016).

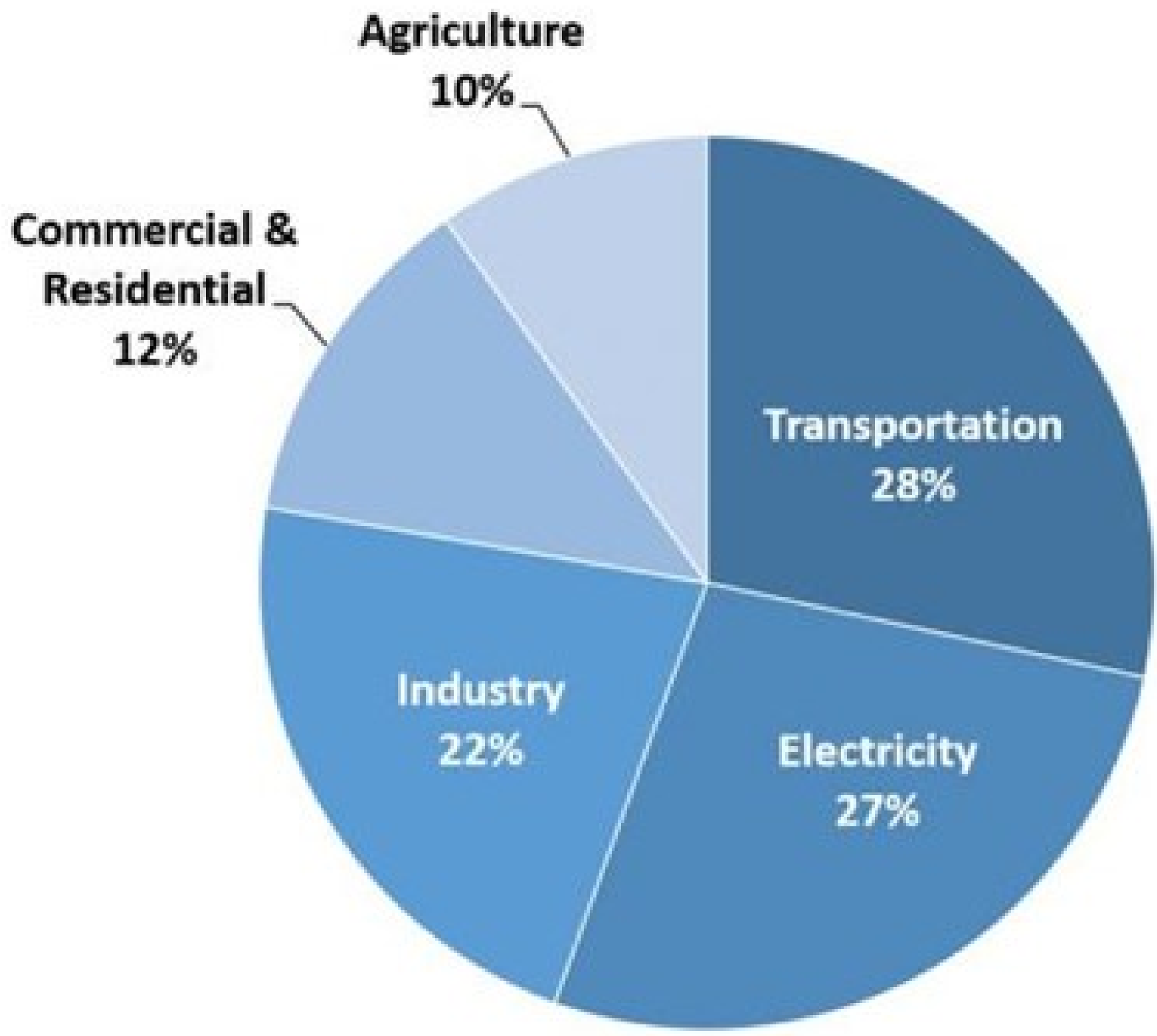

Figure 2: This chart shows the total emissions produced by each major economic sector within the U.S. in 2018, showing the electricity generation and transportation sectors as the two greatest polluters. "Total U.S. greenhouse gas emissions by economic sector in 2018", EPA (2020), United States Environmental Protection Agency, Public Domain.

As society continues to grow digitally and further rely upon technology, the need for electricity will grow along with it, just as the need for transportation will increase with the global population. The need for transportation is one of the more difficult obstacles for what is often referred to as the 'behavioral lock-in', a societal desire that pushes consumers in the direction of popular opinions and needs, such as owning your own car (Seto et al., 2016). The increasing number of drivers who use their own vehicles rather than shared, public transportation is often overlooked, and as more fossil fuel-based automobiles are created and registered for individuals to

drive, the harder it becomes for them to be cycled out by electric cars. With electricity demands growing quickly, it has become difficult to replace existing power structures with cleaner generation methods because of our behavior and technological lock-in. These rapid advancements forced by human behavior upon those in charge of production, invention, and even research make it nearly impossible to swap fuel sources quickly and reliably. There is hope in new technology actively being developed to grab the carbon right out of our atmosphere.

Carbon capture for utilization and storage (CCUS) is the process of taking carbon out of the combustion process for industrial use or for permanent removal from the atmosphere. This technology alone has the potential to reduce carbon emissions from all sources, without having to change the source of fuel. The United Nations Environment Programme and International Energy Agency estimate that carbon capture has the potential to reduce up to 6.3 Gt of CO_2 per year by 2050 (United Nations, 2014).

Industries and researchers have found multiple successful ways to incorporate this technology into current carbon producing energy sources. All CCUS technologies fall into two categories, pre-combustion capture and post-combustion capture. Pre-combustion capture is the process of separating carbon from the fuel source, leaving hydrogen to be burned for energy production (Haszeldine, 2009). Post-combustion capture is the process of absorbing carbon from the gas products of fossil fuel combustion (Haszeldine, 2009). Both processes purify carbon into CO_2, which can be transported for either productive use in industry or for permanent storage.

Both types of CCUS technology have their obvious pros but share the same large con, the process of taking carbon out of fuel requires energy, and therefore costs more money to produce. Current CCUS technology for use in industrial settings has shown a 25-40% energy tax on power plants, however current carbon capture research has the energy tax dropping to 10% and capture efficiency increasing (Haszeldine, 2009). Large energy taxes such as this cause large spikes in cost of electricity, with a U.K. study reporting a cost

increase of 10% per household if carbon capture technology were applied to the energy sector (Haszeldine, 2009).

Despite the current disadvantages these technologies bring, they are a gateway into a new world of renewable energy. The purpose of carbon capture is to reduce the amount of emissions from current harmful practices without having to force a large change on the industries dependent on coal and natural gas (Dwortzan, 2020). CCUS technology also provides a future where clean energy is guaranteed in all circumstances. Renewable energy is a perfect solution to green energy demands but they are not perfectly reliable. A study in the U.K. found that wind power outputs can vary up the 30%, and there are rare weeks where wind energy generation ceases (Haszeldine, 2009). While this unreliability is rare, fossil fuels can be used to generate power on a small scale with carbon capture creating a permanent emission-free future for energy.

Approach and Methodology

We have investigated the ideal combination to use on a small-scale fossil fuel power generator and heating system and are currently collaborating with professionals to work out the application process. We gathered a wide range of information regarding different applications of captured carbon as well as optimal technologies that had significant research and backing, both from larger commercial companies and government agencies. A large portion of our data was gathered through peer-reviewed journals and research papers, all found within our references. The remainder was accumulated from statistics published by government sources and commercial settings. In terms of our contacts, we approached experts both around campus and about carbon capture technology. One such contact was Dr. Eggleston, a civil and environmental engineering head at WPI, who talked us through the analysis required to implement these technologies, as well as the economics

behind creating such a system. Another expert that we reached out to successfully was Mr. Spratt, the director of energy, utilities, and contracted services at the university, who divulged much needed information regarding statistics and information about the power and heat generation site. We are currently still in contact with Dr. Voskian, the creator of the electro-swing technology, about a possible joint venture between WPI, MIT, and his company Verdox. We contacted other companies around the country that deal with CCUS technology in a commercial setting to get a better idea of how operating and maintaining these systems works. We were able to research their patents and use open data to analyze the effectiveness of their solutions on their own relative scale. All this collection was done with the goal of developing a cost benefit analysis and plan for the implementation of a carbon capture system within the WPI natural gas powerhouse.

Findings and Results

Our research on carbon capture included numerous possible technologies that have been developed or are currently being researched. We concluded, based on complexity and data-supported efficiency, that the ideal carbon capture systems are the Allam Cycle and Faradaic Electro-Swing Reactive Adsorption (ESA).

The Allam cycle is a rendition of known **oxy-fuel cycles** that captures all atmospheric emissions from traditional carbon-based fuel sources. The system works by using the supercritical CO_2 and water generated from the combustion of natural gas or coal in pure oxygen to spin a turbine for electricity generation. The gases are then funneled through a water separator, leaving only pure CO_2 left in the system. Then, approximately 5% of the remaining carbon dioxide can be exported out of the system at standard CO_2 piping pressure and temperature, leaving the rest to get pumped back through and reused (Allam et al., 2017).

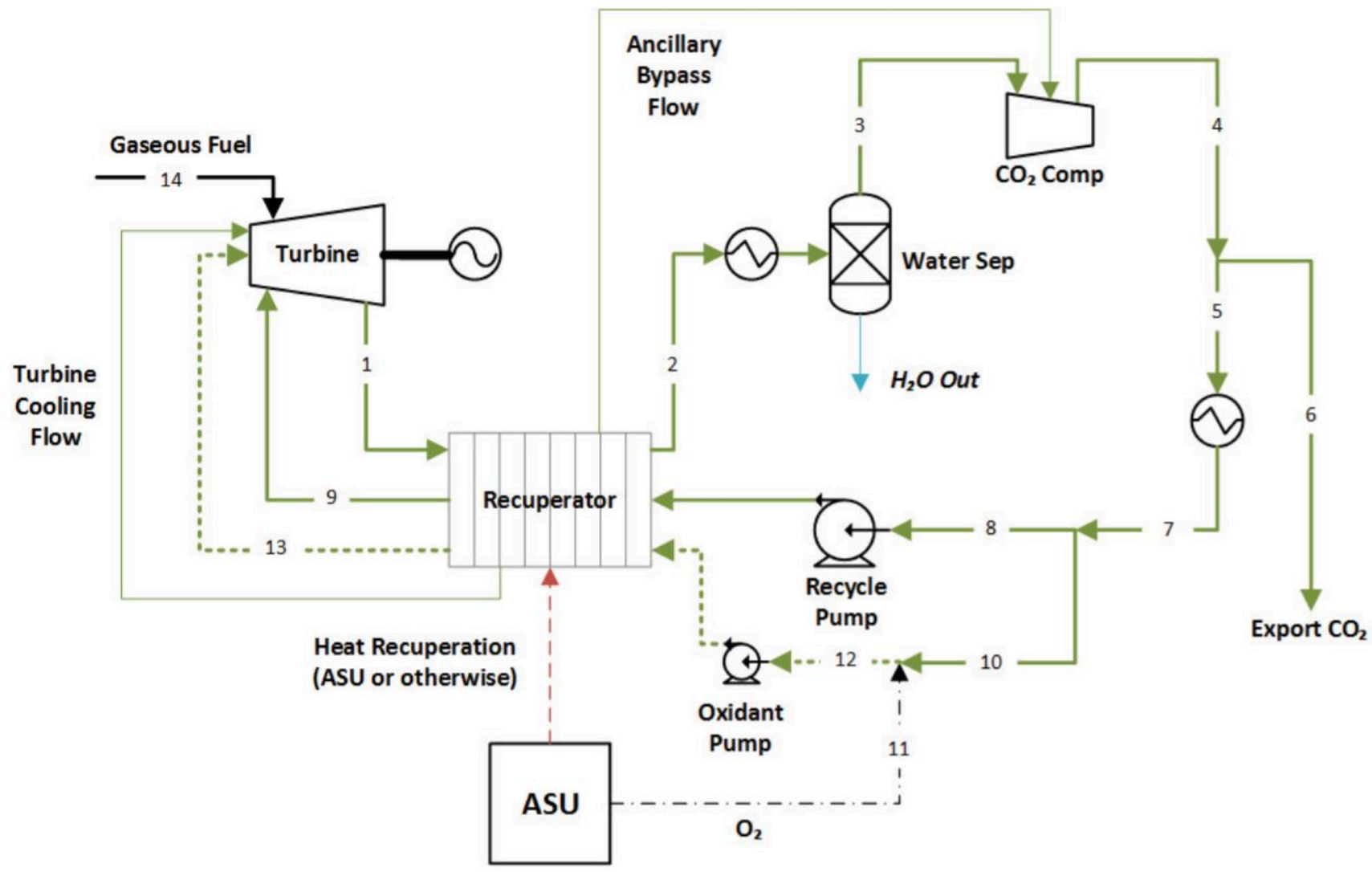

Figure 3: Simplified schematic of commercial scale Allam cycle with a natural gas fuel source. Allam et al. 2017. CC BY-NC-ND 4.0.

This newly developed energy cycle has significant advantages over normal power plants that do not integrate carbon capture systems. It can achieve higher efficiencies, upwards of 59%, with standard energy generation which can only reach up to 50% efficiency (Allam et al., 2017). It should be reiterated that this technology is not inherently a carbon capture device, it is a power cycle that can reliably capture 100% of greenhouse gas emissions.

Faradaic Electro-Swing Reactive Adsorption is a new technology, as of 2019, developed by MIT researchers Dr. Voskian and Dr. Hatton. The system works by running carbon dioxide rich **flue gas** over **electrochemical cells** comprised of polyanthraquinone and polyvinylferrocene electrodes seen in *Figure* 4. The carbon dioxide can saturate the cells by creating voltage swings within the system, this captures carbon dioxide while allowing the remainder of the flue gas to pass through unimpeded (Voskian & Hatton, 2019). This process subsequently charges the cells, putting energy back into the system. Once the electrochemical cells are saturated, flue gas can be cut off and the polarity of the cells reversed. This would release the pure carbon dioxide where it can be directed to a proper containment and storage system. With current innovations in the

technology, the electrodes can go through nearly 100,000 charging cycles before needing replacement. The overall efficiency of the ESA is dependent on the energy inputted, at 90kJ per mole carbon dioxide the system has a 100% capture rate (Voskian & Hatton, 2019). The primary benefit to ESA is its independence of any temperature or pressure differentials typically required in carbon capture technologies. Simply relying on the charging and discharging of electrochemical cells greatly reduces the energy demands of the process and decreases mechanical complexities.

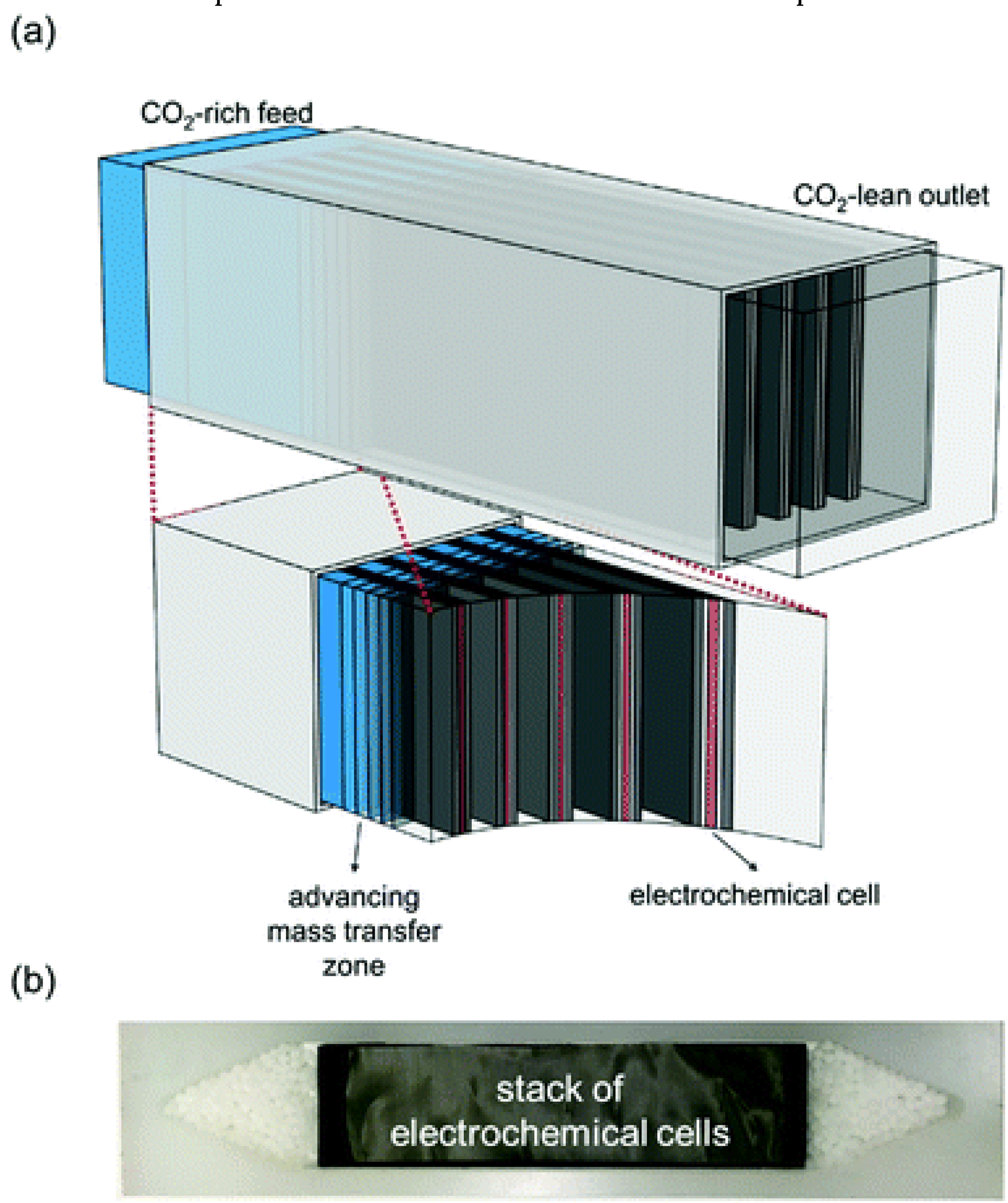

Figure 4: Diagram modeling the electro-swing carbon capture system, image (a) displays the stacked electrochemical cells in contact with

passing carbon dioxide, (b) stack of electrochemical cells. "Figure 7" by Voskian & Hatton, 2019, CC BY-NC 3.0

As for possible applications of the carbon dioxide captured by the implemented technology, there are a plethora of possibilities WPI could begin to practice. Greenhouse enrichment is a commonly used process in which CO_2 is directly released within greenhouses to bolster plant growth by increasing the rate at which photosynthesis occurs. Replacing the unnatural production for this purpose diminishes levels of the harmful gas in the atmosphere and repurposes the byproduct of electricity and heat generation in a robust manner. The carbonation of professional pools is also managed using carbon dioxide, as it is able to balance the pH levels of bodies of water. WPI is an institution that employs this method to keep their indoor pool regulated by purchasing carbon dioxide gas. Piping CO_2 directly captured by the technology implemented would be both a cost-effective and environmentally friendly practice, lowering their emissions rate and cutting spending on pool maintenance (Gunter et al., 1998; Gomà et al., 2010).

As previously stated, storing, and selling any byproduct of energy production is a viable and extremely cost-effective application of the captured gasses. While the resale of this gas cannot guarantee its later emission by other processes, it would offset possible production of unnecessary and harmful greenhouse gases toward our climate. As the world moves toward decarbonization of industry, the amount of CO_2 able to be produced and sold will decrease, raising the prices of the gas linearly over time, generating a large source of revenue for any organization that implements CCUS technology (Luckow et al., 2015).

The WPI on-campus powerhouse is actually a misnomer, rather than generating any power, the building simply houses natural gas boilers used for campus heating. All of the University's 28.7 million kWh of electricity used annually is sourced from the Massachusetts power grid, comprised of various renewable and nonrenewable sources (WPI, 2019). However, the burning of natural gas is still responsible for the output of carbon dioxide. With limited data

available regarding the Universities energy metrics, we calculated that WPI burns 144,648,023 cubic feet of natural gas yearly for its heating demands. Using the average efficiency of natural gas boilers, we found that the campus would emit 7,432 metric tons of carbon dioxide every year from burning the previously mentioned quantity of gas (WPI, 2019).

In order to decide which technology could most reasonably be implemented on the WPI campus, we created a cost benefit analysis to breakdown the real-world investments associated with each solution. *Table 1* pictured below represents the findings of this analysis, showing both the initial and long-term costs associated with the ESA technology. The costs attributed to each carbon dioxide utilization technique were also analyzed to account for all implementation costs more accurately, not depicted in the table.

Table 1: Cost benefit analysis of implementing an electro-swing adsorption system on the WPI campus and the associated expenses.

Capture Technology	Upfront Construction Cost	Operational Power Usage (kWh Per Ton Captured CO_2)	Operation Electricity Cost ($ Per Ton Captured CO_2)	Carbon Dioxide Sales Net Profit Year (Assuming 2021 Construction)	Construction Payoff Year
Electro-Swing Adsorption	$5,000,000	252.47	56.98	2031	2040

Beginning with the three different utilization methods discussed previously; given the rather simple and affordable implementation of both on-campus carbonation and greenhouse enrichment it was decided that both solutions would be viable uses of captured carbon dioxide. However, the relatively large amount of greenhouse gases generated on campus far exceeds the demands of the described solutions. In fact, just 12,201 kg of CO_2 or 1.97% of WPI's yearly emissions could be used by the greenhouse and pool, therefore the remainder of captured carbon would best be sold. Currently, the value of pure CO_2 is increasing at a predictable rate with a current average sales price of $25 per ton. From selling its carbon dioxide, WPI would make more money than the energy cost to operate an ESA system by the year 2031. Profits from carbon dioxide sales would pay off the initial carbon capture cost by the year 2040 (Luckow et al., 2015).

Regarding the capture devices mentioned, the Allam Cycle would require the largest upfront cost at just over $86 million, roughly equivalent to the Smart World building currently in construction at WPI. However, in comparison to ESA, no additional yearly costs would be associated given the plant's ability to generate electricity for campus using the current natural gas heating supply. Implementing this technology on campus would essentially cut off WPI from the grid, allowing the school to generate its own clean energy while selling the byproduct of its energy production. As is present in the following decision matrix, it is important to note the underlying costs in constructing such a large system as the Allam Cycle. These costs include the disruption of movement on campus and the requirement of a new heat generation system for the duration of the construction process.

Although less ambitious, the ESA system would cost only $5 million during the construction process and would be easily integrated within the current powerhouse flue gas piping network. The system would require a space of roughly 20 cubic meters which would easily fit within the space of the powerhouse. While WPI would still be dependent on the Massachusetts power grid for electricity needs, with ESA, the university could continue burning natural gas for heat without emitting carbon dioxide. In order to operate the ESA system, additional power is required, roughly 2 million kWh per year. Buying this electricity from the grid would cost an average of $423,000 yearly, however, given the remaining nonrenewable energy sources that makeup the Massachusetts grid, this additional energy would likely result in indirect statewide increased carbon emissions. However, with the previously mentioned sales market for pure carbon dioxide, these additional costs could be offset by the sale of campus captured CO_2, essentially negating the additional yearly energy expenses associated with the operation of ESA.

To determine the best carbon capture technology for implementation on a small scale we created a decision matrix to further analyze the options each solution may bring. The following

decision matrix will generate a solution for the ideal carbon capture technology to implement on campus with the idea that various carbon utilization methods would be used in tandem on a small scale such as the WPI campus.

Decision Matrix Criteria:

The following is a list of criteria that we used to further narrow our potential solutions based on both primary and secondary source material.

- *Affordability*: Is the solution relatively inexpensive? How will the system pay itself forward over time?
- *Efficiency*: How efficient is the system at either capturing carbon or using carbon dioxide? How does it affect existing system efficiencies?
- *Integration*: How easily can the technology be integrated with existing systems? Will it require any reconfiguration of utilities?
- *Impact*: What is the environmental impact of the technology or utilization method? What is the overall benefit?
- *Scale*: What is the size of the system and how easily can it be scaled based on demand or necessity?
- *Reliability*: Is the system reliable? What will maintenance look like? What are potential issues that could arise and how could they be mitigated?

Decision Matrix Weights:

The following is a list of the designated weights assigned to each of the above criteria based on the criteria's significance to the outlined goals and objectives made by both primary and secondary sources and contacts.

- *Affordability* (20%): The system must be economically feasible on a small scale and pay itself off over time.
- *Efficiency* (20%): The system must be highly efficient at either capturing or reusing captured carbon.

- *Integration* (20%): The technology must be easy to integrate within existing systems and utilities.
- *Impact* (15%): The solution must be environmentally friendly and significantly decrease the carbon footprint of WPI.
- *Scale* (15%): The system must be able to fit within the WPI campus, and more specifically be implemented within the confines of the boiler room.
- *Reliability* (10%): The system must be low maintenance and have a relatively low number of possible problems.

Table 2. Applied Decision Matrix to Faradaic Electro-Swing Reactive Adsorption and Allam Cycle Technologies. Scores are given based on their importance above, each criterion can only give as many points as their percent importance.

Category	ESA	Allam Cycle
Affordability (Max 20)	14	6
Efficiency (Max 20)	16	20
Integration (Max 20)	19	0
Impact (Max 15)	15	15
Scale (Max 15)	13	3
Reliability (Max 10)	7	8
Total	**84**	**52**

Conclusions

We finally concluded that the Faradaic Electro-Swing Reactive Adsorption method had the greatest chance of success and proper implementation on campus. The scalability, lower cost, faster turnaround rate for building the device, and lower operational cost per ton of CO_2 were the deciding factors in the end. The success

of our recommendation has a couple different ways in which it can be measured. The most obvious measure for success is a lower CO_2 emission rate on campus, as the permanent sequestration of carbon is the overall goal for both our project and mitigating climate change.

The use of this technology on campus has no potential risks because it in no way changes the dynamics of current natural gas boilers. The utilization of the captured carbon is an already safe system because carbon pipelines and transportation trucks have been used around the country for decades. All quality specifications defined by the UNC Energy Center for pipeline CO_2 are met by the output from the Faradaic Electro-Swing Reactive Adsorption system.

The implementation of the ESA system on the Worcester Polytechnic Institute campus would have major benefits for the institution. With this successful carbon capture device, WPI could significantly lower its projected emissions on a very short time scale, while also creating a source of revenue that will decrease electricity costs after just a decade. As an almost carbon neutral campus, prospective students would come to the institution with passion for climate change mitigation and use its resources to spark research into global sustainability efforts.

The campus of WPI can be used as a pilot project for the implementation of this technology. With this foundation, other universities and academic institutions can look into developing the technology further or implementing other promising carbon capture technologies within their communities. This rapid improvement of CCUS technology has the potential of creating cheap and effective solutions that assist the world in quickly reducing carbon emissions.

Recommendations

Many paths can be taken to cut down on greenhouse gas emissions and begin to restore the global climate, and CCUS technology is just one such avenue that showed great potential. The conclusion derived from the research done only looked into the scope of how feasible the implementation would be at WPI and did not encompass plans to go fourth and actually change the infrastructure of campus. Other steps would need to be taken in order to successfully generate and carry out such a plan. A consultation with administrators and the president of the University would need to occur, in which approval and possible methods of funding would need to be given and discussed before the project can begin.

Once both of those have been received, other parties such as Dr. Voskian, contractors, and the WPI administrative board would have to craft a more detailed model of costs, construction plans, and a timetable on implementation to prepare for the introduction of CCUS. Contracts and research done individually by all parties would need to be drafted as well to solidify plans and ensure a successful transition.

See Appendix 4 for the infographic used by the team on Project Presentation Day.

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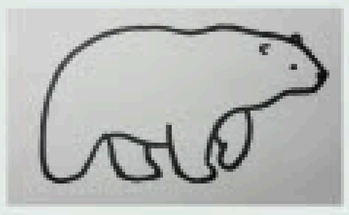
Appendix

Appendix 1. Infographic used in Project Presentation Day for the Rigged for Oil Rigs project. Final_Arctic_Drilling_Infographic

RIGGED FOR OIL RIGS

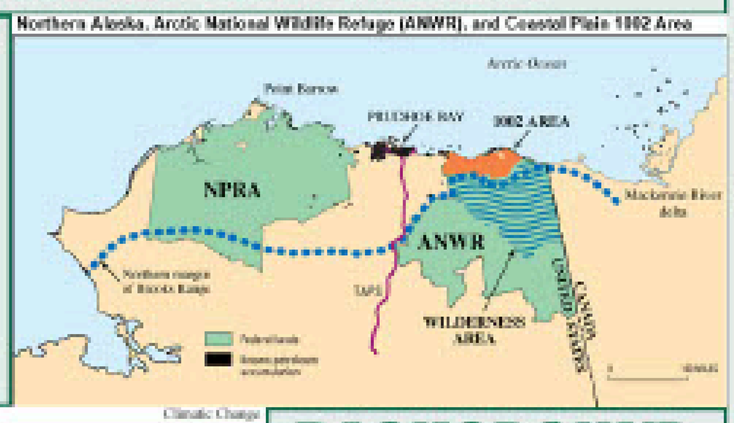


The Political Polar Bears

Nora Smith, Katherine Corbin, Gabe Ward

OUR GOAL

Our goal is to learn how the US has approached Arctic drilling through different lenses: Economy and Environment



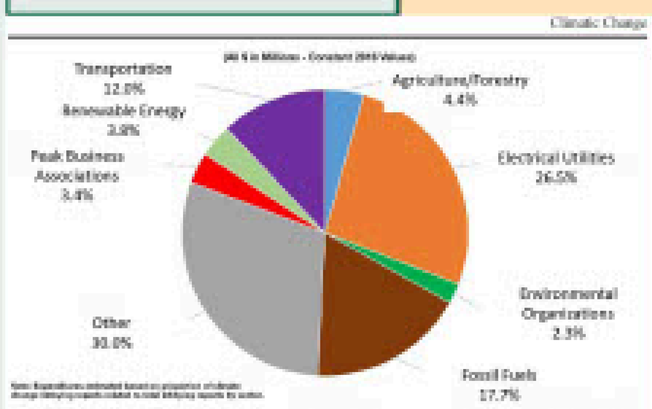


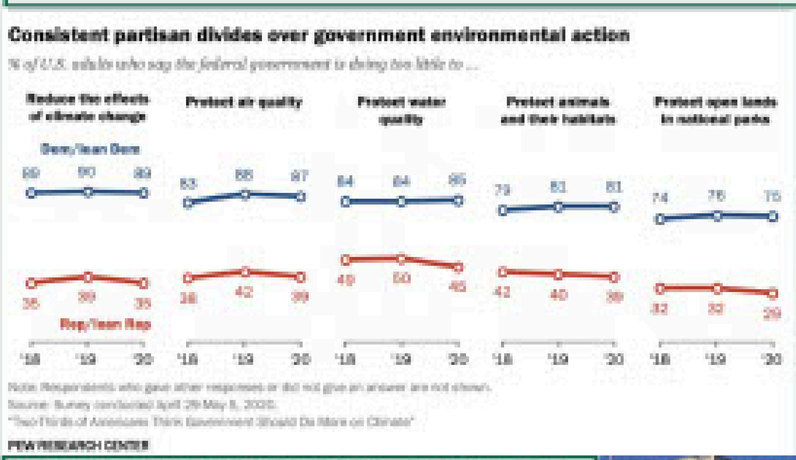
Fig. 3 US national climate change lobbying expenditures distribution of spending by sector, 2000 to 2016

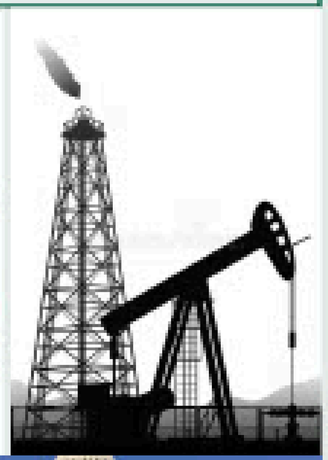
BACKGROUND

- The ANWR is one of the last untouched refuges
  - Area of 19 million acres in northeastern Alaska
- Oil companies and the government prioritize profit for sustainability

ASSESSEMENT OF THE PROBLEM

- The ANWR was opened for bidding in late 2020
  - This accumulated a total profit of 14.4 million dollars
  - This harms the habitat of many endangered species





RAISING AWARENESS

- Through contacts with different organizations
- Advocating for protests to enact change
- Raising awareness will put pressure on the government to take legal steps

Appendix 2. Infographic used in Project Presentation Day for the Climate Change Impacts on Native Hawaiian Population project. Climate_Change_Effects_on_Native_Hawaiian_Population__1_

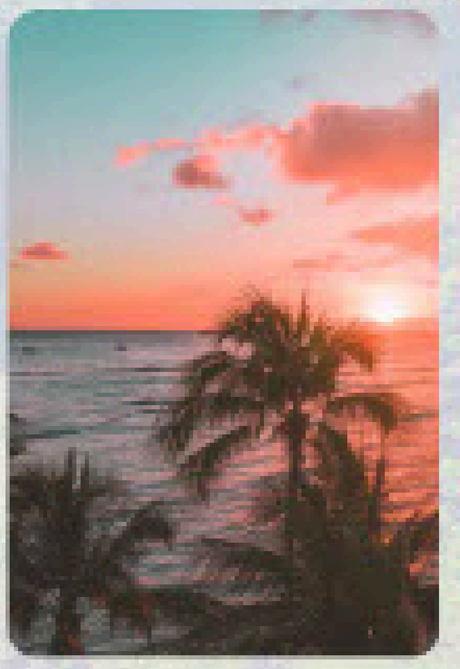
Climate Change Effects on Native Hawaiian Population

By Katherine Miller, Elizabeth Dahlberg, and Isabella Clowes

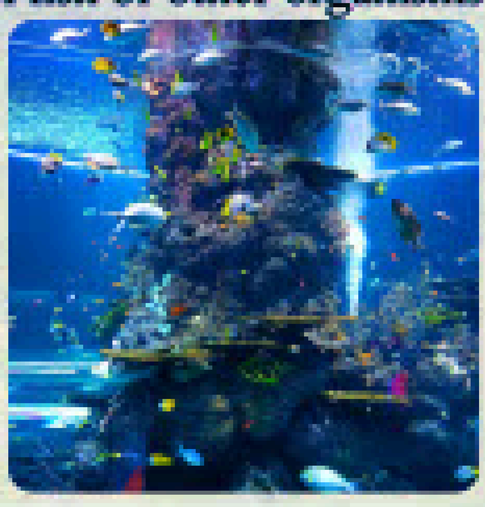
Indigenous Hawaiians are disproportionately affected by climate change due to their reliance on natural resources and cultural ties to the land

Tourism is a huge part of Hawaii's economy. Most visitors come to experience the unique native Hawaiian culture and the beauty of Hawaii's tropical beaches and reefs.

Beach erosion causes estimated loss of $2.2 billion per year of tourism revenue in Waikiki alone



Coral reefs are suffering from bleaching events leading to a loss of biodiversity in fish or other organisms



WHAT DO WE RECOMMEND?

Coral Gardening

Coral gardening works by collecting small coral fragments from struggling reefs and moving them into a nursery where they are monitored and nurtured
Then, once the corals have grown up, the healthy corals are returned to the reefs

Hawaii's tourism industry also depends on coral reefs, with reef activities bringing in about $304 million annually for the state

Shoreline Hardening

Appendix 3. Infographic used in Project Presentation Day for the Destigmatizing Nuclear Energy to Decarbonize the Worlds' Power Supply project. Reducing_Nuclear_Stigma

Appendix 4. Infographic used in Project Presentation Day for the Small Scale Carbon Capture implementation and Utilization project. Campus Carbon Capture