The Mothers of the Disappeared still gather around the Plaza de Mayo; they still seek a full accounting for the acts of state terrorism under the military junta of the 1970s. Students in China are fighting battles fought by their parents and grandparents. Latin Americans celebrate democratic and independence movements that go back hundreds of years, but that have still not been fully realized. Indeed, in the Americas and the rest of the world the goalposts have moved since the days when democratic states accepted enslaved Africans, invisible Indians, and colonial subjects. Recent claims for human rights, freedom from sexual or gender discrimination, and international jurisdiction over war crimes and genocide are all extensions of our democratic expectations. Failure or retrenchment can be seen as the setting of the next battle rather than a sign that democracy failed or, worse, that it doesn't work.

Democratic demands in the twenty-first century reach further than ever before. Likewise, the conditions for achieving democracy have also expanded. A democracy that was limited to white men of the propertied class could function with an educational system that ignored everyone else. A mass democracy requires a mass citizenry educated to think and participate intelligently. It requires what Franklin D. Roosevelt called "freedom from want" to allow all citizens the time and resources to participate. And it requires the level playing field, unencumbered by special interests with private agendas. The effort to create the public space where citizens can create their common world continues.

27

Global Warming and Climate Change

The World, 1900 to the Present

■ HISTORICAL CONTEXT

Climate change is dismissed by some, especially in the United States, as a nonissue: "The climate is always changing," they say; "You can't change the weather." But climate and weather are quite different. Weather is the short-term variation within the longer-term multi-year changes in climate. And while tomorrow's weather forecast may be cooler or warmer than today's, the climate is warming a degree or two a century since the beginning of the industrial revolution. Because the industrial revolution was powered by the burning of fossil fuels like coal, oil, and gas—which increases the carbon in the atmosphere, creating a greenhouse effect that warms the atmosphere—we know that, regardless of any natural variations occurring, it is people and the decisions they make that are causing the warming of the planet. In this chapter we explore the history of that discovery, with examples of climate change and its implications and with responses to the problem.

■ THINKING HISTORICALLY

Keeping the Individual in the Global

The understanding of world history requires us to view it as a large canvas, but in doing so, there is the danger of losing sight of individuals. How do we ensure that our understanding of global change is not so abstract that it loses relevance to human beings? How do we tell the stories of people and the planet without losing the perspective of one

or the other? In this chapter on environmental change, we will discuss what we can learn from individuals while considering how biography and global history can inform each other. This perspective enables us to consider what an individual can do.

1

IAN SAMPLE

Arrhenius: The Father of Climate Change in 1896, 2005

This essay recalls the work of an unsung scientist in Sweden at the end of the nineteenth century. As you read the selection, keep in mind the following questions: What did he discover? How did his work lead to the development of climate science? How has climate science evolved since then? How is climate science especially a global issue?

THINKING HISTORICALLY

It may be a stretch to call Arrhenius "the father of climate change," but if we translate that metaphor to mean the originator of the science of climate change and we tell his story, what do we learn about climate change that we might not have learned otherwise? Keep in mind the following questions as you read the selection: How does the story of individual discoveries lead us to different questions than the story of the actual changes? What was Arrhenius's initial feeling about the effects of climate change? How, why, and when did climate science become worrisome?

Behind the tree-lined embankment that borders the campus of Stockholm University lies building 92E, a red brick villa as big as a fire station, its back turned to Roslagsvägen, the main artery linking the capital city with Norrtälje 70km away.

What few markings there are on the building suggest nothing of its history. A sign above the entrance identifies it as Cafe Bojan, a student canteen, and a few shirtless students on a bench in the morning sun recall it as nothing more.

Ian Sample, "Arrhenius: the father of climate change," *The Guardian*, June 30, 2005.

At the end of the 19th century, building 92E was the home and laboratory of Svante Arrhenius, a chemist who became Sweden's first Nobel prizewinner. He was destined to have a bigger impact than he could have imagined, far beyond his mainstream work. Unwittingly, he uncovered secrets of the Earth's atmosphere and in doing so triggered research into what many see as the biggest threat to modern humans. He is arguably the father of climate change science.

That title would be a surprise, even to him. The son of a land surveyor, Arrhenius thrived at school, showing a particular aptitude for arithmetic, but his diversity of thought and penchant for maverick theories dealt him a hefty blow at university. His PhD research, which he began at Uppsala University to the north of Stockholm, focused on the conductivity of electrolytes, but the ideas he put forward in his thesis baffled his professors and he was awarded the lowest possible pass grade. At once, any hopes of staying on at Uppsala were destroyed, and Arrhenius embarked on a tour of European laboratories before landing a job in Stockholm several years later.

Arrhenius became interested in a debate occupying the scientific community, namely the cause of the ice ages. Could it be, he wondered, that vast swings in the levels of atmospheric CO_2, lasting tens of millions of years, were the trigger?

The link between CO_2 and the Earth's temperature had been made years beforehand. It was the French scientist Joseph Fourier who first realized that certain atmospheric gases shrouded the planet like a bell jar, transparent to sunlight, but absorbing to infrared rays. It means the atmosphere is heated from above and below: first, by sunlight as it shines through and second by the infrared the Earth emits as it cools overnight.

Arrhenius set himself the task of working out just how much water and CO_2 in the atmosphere warmed the planet. From others' work, he knew that CO_2 was only part of the process. While CO_2 and other gases trapped infrared radiation and so heated the atmosphere, warmer air holds more water vapor, itself the most potent contributor to the greenhouse effect. So, if atmospheric CO_2 levels increased, water vapor would ensure the warming effect was seriously magnified.

What followed was a year doing what Arrhenius described as "tedious calculations." His starting point was a set of readings taken by US astronomer Samuel Langley, who had tried to work out how much heat the Earth received from the full moon. Arrhenius used the data with figures of global temperatures to work out how much of the incoming radiation was absorbed by CO_2 and water vapor, and so heated the atmosphere.

Between 10,000 and 100,000 calculations later, Arrhenius had some rough, but useful, results that he published in 1896. If CO_2 levels halved, he concluded, the Earth's surface temperature would fall by 4–5C. There was a flipside to his calculations: doubling CO_2 levels would trigger a rise of about 5–6C.

Beyond the argument over ice ages it wasn't lost on Arrhenius that human activity, in the form of widespread burning of coal, was pumping atmospheric CO_2 above the natural levels that help make the Earth habitable. Almost as a passing comment, he estimated that coal burning would drive a steady rise in CO_2 levels of about 50% in 3,000 years, a prospect he found entirely rosey. At a lecture that same year, he declared: "We would then have some right to indulge in the pleasant belief that our descendants, albeit after many generations, might live under a milder sky and in less barren surroundings than is our lot at present."

As the first to put hard figures on the greenhouse effect, it's unsurprising Arrhenius's estimates weren't spot on. He thought it would take millennia to see a 50% rise in CO_2—but modern measurements show a 30% rise during the 20th century alone. He thought a doubling of CO_2 would raise temperatures by 5–6C. Scientists now say 2–3C is more likely.

Over the next decades, his work was criticized, backed up and criticized again. Many disregarded his conclusions, pointing to his simplification of the climate and how he failed to account for changes in cloud cover and humidity. The oceans would absorb any extra CO_2 pumped into the atmosphere, and any remainder would be absorbed by plant life, leading to a more lush landscape, sceptics argued.

In 1938, nine years after Arrhenius had died, a Nobel prizewinner for his work on ionic solutions, English engineer Guy Callendar gave the greenhouse theory a boost. An expert on steam technology, he took up meteorology as a sideline and became interested in suggestions of a warming trend. Callendar pieced together temperature measurements from the 19th century onwards and saw an appreciable rise. He went on to check CO_2 over the same period and discovered levels had increased about 10% in 100 years. The warming was probably due to the higher levels of CO_2.

The existence of an increasing greenhouse effect was hotly debated until the postwar funding of the 1950s kicked in and researchers began to get firm data. In 1956, physicist Gilbert Plass confirmed adding CO_2 to the atmosphere would increase infrared radiation absorbed, adding that industrialization would raise the Earth's temperature by just over 1C per century. By the end of the 1950s, Plass and other scientists in the US started warning government officials that greenhouse warming might become a serious issue in the future.

Unwittingly, the US especially had already started monitoring what many believed were the direct effects of a warming world. Submarines operating in the Arctic Circle took accurate readings of the thickness of the ice sheets above them. When the Pentagon released the data nearly 40 years later, it revealed a startling melting of the ice, on average a 40% thinning of 1.3m since 1953.

In the 1960s, researchers at Scripps Institution of Oceanography in San Diego took on the testing challenge of taking a vast number of measurements of atmospheric CO_2. The aim was to establish a baseline level with which future readings in a decade or so could be compared.

Charles Keeling spent two years taking measurements in Antarctica and above the Mauna Loa volcano in Hawaii but reported that even in this short period, CO_2 levels had risen. He concluded that the oceans weren't absorbing greenhouse gases being pumped out by industry. Instead, emissions were driving levels of CO_2 higher. "It was a seminal discovery. For the first time, scientists knew that the oceans weren't going to absorb all this carbon dioxide," says Mike Hulme at the Tyndall Centre for climate change research at the University of East Anglia.

Still, few saw the greenhouse effect and the warming it would bring as being a problem. At the time, computer models were suggesting modest increases, perhaps 2C in hundreds of years.

By the 1980s, climate change had become a megascience, attracting scientists from diverse fields, each attacking the problem from a different angle. One technique was especially useful. Deep cores of ice cut from Greenland and elsewhere held pockets of air dating back hundreds of thousands of years. By analyzing the trapped air, scientists worked out CO_2 levels in the atmosphere during past ice ages. In 1987, a core cut from central Antarctica showed that in the previous 400,000 years, CO_2 had dropped to 180 parts per million (ppm) during the most extreme glacial periods and climbed as high as 280ppm in warmer times, but not once had been higher. In the outside air, CO_2 was measured at 350ppm, unprecedented for nearly half a million years.

To mainstream scientists, evidence that warming was due to human activity was becoming too big to ignore. While scientists uncovered evidence for the greenhouse effect and warming it was producing, others pointed to different processes impacting on global climate. Volcanos, for example, blast millions of tons of sulphur dioxide into the atmosphere that form aerosol particles which reflect sunlight back into space. The 1991 eruption of Mount Pinatubo in the Philippines sent about 20m tons of the gas into the atmosphere, leading to a global cooling of around 0.5C a year later. Scientists now believe that the warming experienced in the early 20th century can largely be explained by the lack of volcanic activity.

Variations in the sun's intensity have also been fingered as a driver of climate change. According to Joanna Haigh at Imperial College London, about a third of the warming since 1850 can be explained by solar activity. The identification of disparate contributors to warming has been seized upon by a minority who claim global warming is driven far more by nature than human activity, and the ensuing controversy is still not settled.

By 1988, the United Nations had established the Intergovernmental Panel on Climate Change to review relevant research. The panel's latest estimate points to a warming of 1.4–5.8C by 2100, depending on what strategies, if any, are adopted to curb emissions. The 20th century saw a rise in temperature of 0.6C, about half of which occurred since 1970.

Arguably the most concerted effort to cut global emissions has been triggered by the Kyoto Protocol. Since ratification began in 1997, more than 100 countries have adopted the protocol, which for the first time committed them to cutting emissions of six greenhouse gases.

Now, barely a week goes by without a major study on climate change. A flurry of papers started the year with warnings that the Gulf Stream would grind to a halt, ski resorts would move to higher altitudes and Antarctic glaciers were melting fast. More than 100 years after Arrhenius set out to discover why the world fell into periodic ice ages, the scientist has become a pillar of the megascience that is global warming research.

Back in Stockholm's meteorology department, Erland Kallen is musing about progress since Arrhenius first set about his calculations. "Even when I came to this field 20 years ago, I was very skeptical about global warming. There were too many uncertainties. I just couldn't see how anyone could say anything sensible about it. Now, I struggle to see what other explanation there could be."

2

MARGARET THATCHER

Speech to United Nations on Global Environment, 1989

Margaret Thatcher (1925–2013) was the British Prime Minister from 1979 to 1990. Like her conservative ally at the time, President Ronald Reagan (1911–2004) in the United States from 1981 to 1989, she swept away much of the worker protections and social safety net of the post–World War II welfare state, favored private and corporate interests over public and governmental activities, and voiced a bellicose stance against the Soviet Union and anything resembling socialism. But Thatcher was originally a scientist. She told her fellow members of the Royal Society in 1989 that while she was content with giving up her work on glyceride monolayers in the 1950s in order to enter politics, she shared the belief of English mathematician and philosopher Alfred North Whitehead "that a nation which does not value trained intelligence is doomed."[1] As you read the selection, keep in mind the following questions: How did Thatcher's interest in science relate to her environmental concerns? What did Thatcher want the United Nations to do in response to climate change?

Margaret Thatcher, Speech to United Nations General Assembly (Global Environment), Nov. 8, 1989, https://www.margaretthatcher.org/document/107817.

THINKING HISTORICALLY

Margaret Thatcher makes her argument in the selection by inviting us into the mind of Charles Darwin and other individuals as she speaks to the United Nations General Assembly. Keep in mind the following questions as you read the selection: How does Thatcher make their experience our own? How does that strategy enhance her argument? What does she urge individuals to do?

Mr. President, it gives me great pleasure to return to the Podium of this assembly. When I last spoke here four years ago, on the 40th anniversary of the United Nations, the message that I and others like me gave was one of encouragement to the organisation to play the great role allotted to it.

Of all the challenges faced by the world community in those four years, one has grown clearer than any other in both urgency and importance—I refer to the threat to our global environment. I shall take the opportunity of addressing the general assembly to speak on that subject alone.

Introduction

During his historic voyage through the south seas on the *Beagle*, Charles Darwin landed one November morning in 1835 on the shore of Western Tahiti.

After breakfast he climbed a nearby hill to find a vantage point to survey the surrounding Pacific. The sight seemed to him like "a framed engraving," with blue sky, blue lagoon, and white breakers crashing against the encircling Coral Reef.

As he looked out from that hillside, he began to form his theory of the evolution of coral; 154 years after Darwin's visit to Tahiti we have added little to what he discovered then.

What if Charles Darwin had been able, not just to climb a foothill, but to soar through the heavens in one of the orbiting space shuttles?

[1] Margaret Thatcher Foundation, https://www.margaretthatcher.org/document/107346.

What would he have learned as he surveyed our planet from that altitude? From a moon's eye view of that strange and beautiful anomaly in our solar system that is the earth?

Of course, we have learned much detail about our environment as we have looked back at it from space, but nothing has made a more profound impact on us than these two facts.

First, as the British scientist Fred Hoyle wrote long before space travel was a reality, he said "once a photograph of the earth, taken from the outside is available . . . a new idea as powerful as any other in history will be let loose."

That powerful idea is the recognition of our shared inheritance on this planet. We know more clearly than ever before that we carry common burdens, face common problems, and must respond with common action.

And second, as we travel through space, as we pass one dead planet after another, we look back on our earth, a speck of life in an infinite void. It is life itself, incomparably precious, that distinguishes us from the other planets.

It is life itself—human life, the innumerable species of our planet—that we wantonly destroy. It is life itself that we must battle to preserve.

For over forty years, that has been the main task of this United Nations.

To bring peace where there was war.

Comfort where there was misery.

Life where there was death. . . .

While the conventional, political dangers—the threat of global annihilation, the fact of regional war—appear to be receding, we have all recently become aware of another insidious danger.

It is as menacing in its way as those more accustomed perils with which international diplomacy has concerned itself for centuries.

It is the prospect of irretrievable damage to the atmosphere, to the oceans, to earth itself.

Of course major changes in the earth's climate and the environment have taken place in earlier centuries when the world's population was a fraction of its present size.

The causes are to be found in nature itself—changes in the earth's orbit: changes in the amount of radiation given off by the sun: the consequential effects on the plankton in the ocean: and in volcanic processes.

All these we can observe and some we may be able to predict. But we do not have the power to prevent or control them.

What we are now doing to the world, by degrading the land surfaces, by polluting the waters and by adding greenhouse gases to the air at an unprecedented rate—all this is new in the experience of the earth. It is mankind and his activities which are changing the environment of our planet in damaging and dangerous ways.

We can find examples in the past. Indeed, we may well conclude that it was the silting up of the River Euphrates which drove man out of the Garden of Eden.

We also have the example of the tragedy of Easter Island, where people arrived by boat to find a primeval forest. In time the population increased to over 9,000 souls and the demand placed upon the environment resulted in its eventual destruction as people cut down the trees. This in turn led to warfare over the scarce remaining resources and the population crashed to a few hundred people without even enough wood to make boats to escape.

The difference now is in the scale of the damage we are doing.

Vast Increase in Carbon Dioxide

We are seeing a vast increase in the amount of carbon dioxide reaching the atmosphere. The annual increase is three billion tonnes: and half the carbon emitted since the Industrial Revolution still remains in the atmosphere.

At the same time as this is happening, we are seeing the destruction on a vast scale of tropical forests which are uniquely able to remove carbon dioxide from the air.

Every year an area of forest equal to the whole surface of the United Kingdom is destroyed. At present rates of clearance, we shall, by the year 2000, have removed 65 percent of forests in the humid tropical zones.

The consequences of this become clearer when one remembers that tropical forests fix more than ten times as much carbon as do forests in the temperate zones.

We now know, too, that great damage is being done to the Ozone Layer by the production of halons and chlorofluorocarbons. But at least we have recognised that reducing and eventually stopping the emission of CFCs is one positive thing we can do about the menacing accumulation of greenhouse gases.

It is of course true that none of us would be here but for the greenhouse effect. It gives us the moist atmosphere which sustains life on earth. We need the greenhouse effect—but only in the right proportions.

More than anything, our environment is threatened by the sheer numbers of people and the plants and animals which go with them. When I was born the world's population was some 2 billion people. My grandson will grow up in a world of more than 6 billion people.

Put in its bluntest form: the main threat to our environment is more and more people, and their activities: The land they cultivate ever more intensively; The forests they cut down and burn; The mountain sides they lay bare; The fossil fuels they burn; The rivers and the seas they pollute.

The result is that change in future is likely to be more fundamental and more widespread than anything we have known hitherto. Change to the sea around us, change to the atmosphere above, leading in turn to change in the world's climate, which could alter the way we live in the most fundamental way of all.

That prospect is a new factor in human affairs. It is comparable in its implications to the discovery of how to split the atom. Indeed, its results could be even more far-reaching.

The Latest Scientific Evidence

We are constantly learning more about these changes affecting our environment, and scientists from the Polar Institute in Cambridge and The British Antarctic Survey have been at the leading edge of research in both the Arctic and the Antarctic, warning us of the greater dangers that lie ahead.

Let me quote from a letter I received only two weeks ago, from a British scientist on board a ship in the Antarctic Ocean: he wrote, "In the Polar Regions today, we are seeing what may be early signs of man-induced climatic change. Data coming in from Halley Bay and from instruments aboard the ship on which I am sailing show that we are entering a Spring Ozone depletion which is as deep as, if not deeper, than the depletion in the worst year to date. It completely reverses the recovery observed in 1988. The lowest recording aboard this ship is only 150 Dobson units for Ozone total content during September, compared with 300 for the same season in a normal year." That of course is a very severe depletion.

He also reports on a significant thinning of the sea ice, and he writes that, in the Antarctic, "Our data confirm that the first-year ice, which forms the bulk of sea ice cover, is remarkably thin and so is probably unable to sustain significant atmospheric warming without melting. Sea ice separates the ocean from the atmosphere over an area of more than 30 million square kilometres. It reflects most of the solar radiation falling on it, helping to cool the earth's surface. If this area were reduced, the warming of earth would be accelerated due to the extra absorption of radiation by the ocean."

"The lesson of these Polar processes," he goes on, "is that an environmental or climatic change produced by man may take on a self-sustaining or 'runaway' quality . . . and may be irreversible." That is from the scientists who are doing work on the ship that is presently considering these matters.

These are sobering indications of what may happen and they led my correspondent to put forward the interesting idea of a World Polar Watch, amongst other initiatives, which will observe the world's climate system and allow us to understand how it works.

We also have new scientific evidence from an entirely different area, the Tropical Forests. Through their capacity to evaporate vast volumes of water vapour, and of gases and particles which assist the formation of clouds, the forests serve to keep their regions cool and moist by weaving a sunshade of white reflecting clouds and by bringing the rain that sustains them.

A recent study by our British Meteorological Office on the Amazon rainforest shows that large-scale deforestation may reduce rainfall and thus affect the climate directly. Past experience shows us that without trees there is no rain, and without rain there are no trees.

The Scope for International Action

Mr President, the evidence is there. The damage is being done. What do we, the International Community, do about it?

In some areas, the action required is primarily for individual nations or groups of nations to take.

I am thinking for example of action to deal with pollution of rivers—and many of us now see the fish back in rivers from which they had disappeared.

I am thinking of action to improve agricultural methods—good husbandry which ploughs back nourishment into the soil rather than the cut-and-burn which has damaged and degraded so much land in some parts of the world.

And I am thinking of the use of nuclear power which—despite the attitude of so-called greens—is the most environmentally safe form of energy.

But the problem of global climate change is one that affects us all and action will only be effective if it is taken at the international level.

It is no good squabbling over who is responsible or who should pay. Whole areas of our planet could be subject to drought and starvation if the pattern of rains and monsoons were to change as a result of the destruction of forests and the accumulation of greenhouse gases.

We have to look forward not backward and we shall only succeed in dealing with the problems through a vast international, co-operative effort. . . .

Conclusion

Mr. President, the environmental challenge which confronts the whole world demands an equivalent response from the whole world. Every country will be affected and no one can opt out.

We should work through this great organisation and its agencies to secure world-wide agreements on ways to cope with the effects of climate change, the thinning of the Ozone Layer, and the loss of precious species.

We need a realistic programme of action and an equally realistic timetable.

Each country has to contribute, and those countries who are industrialised must contribute more to help those who are not.

The work ahead will be long and exacting. We should embark on it hopeful of success, not fearful of failure.

I began with Charles Darwin and his work on the theory of evolution and the origin of species. Darwin's voyages were among the high-points of scientific discovery. They were undertaken at a time when men and women felt growing confidence that we could not only understand the natural world but we could master it, too.

Today, we have learned rather more humility and respect for the balance of nature. But another of the beliefs of Darwin's era should help to see us through—the belief in reason and the scientific method.

Reason is humanity's special gift. It allows us to understand the structure of the nucleus. It enables us to explore the heavens. It helps us to conquer disease. Now we must use our reason to find a way in which we can live with nature, and not dominate nature.

At the end of a book which has helped many young people to shape their own sense of stewardship for our planet, its American author quotes one of our greatest English poems, Milton's "Paradise Lost."

When Adam in that poem asks about the movements of the heavens, Raphael the Archangel refuses to answer. "Let it speak," he says,

> "The Maker's high magnificence, who built
> So spacious, and his line stretcht out so far,
> That Man may know he dwells not in his own;
> An edifice too large for him to fill,
> Lodg'd in a small partition, and the rest
> Ordain'd for uses to his Lord best known."

We need our reason to teach us today that we are not, that we must not try to be, the lords of all we survey.

We are not the lords, we are the Lord's creatures, the trustees of this planet, charged today with preserving life itself—preserving life with all its mystery and all its wonder.

May we all be equal to that task.

Thank you Mr. President.

3

JOHN H. CUSHMAN JR.

Harvard Study Finds Exxon Misled Public about Climate Change, 2017

Margaret Thatcher was not only a scientist; as Conservative Party Prime Minister she was a beacon of the conservative movement that swept through Britain and the Republican party of the United States in the 1980s. Ronald Reagan and George H. W. Bush echoed Thatcher's concerns about global warming, urging their administrations to take an active role leading the world community to solve the problem. But the enthusiasm of the Republican Party ran aground as the interests of the fossil fuel industry became more relevant. Exxon (Exxon Mobil after 1999) was one of the most influential voices to raise skepticism about climate science, running regular ads questioning what had privately become its own conclusions. The charge that Exxon misled the public and its shareholders about its impact on climate change has reached the courts. Other companies that had a vested interest in fossil fuels may follow. As you read the selection, keep in mind the following questions: What is the nature of this charge? What evidence is presented in the study?

THINKING HISTORICALLY

Keep in mind the following questions as you read the selection: What role have individuals, named and unnamed, played in the acts charged, their discovery, the reporting to the public, and the response of the justice system? What do these examples suggest to you about the impact individuals can have on broad processes like climate change?

A comprehensive, peer-reviewed academic study[1] of ExxonMobil's internal deliberations, scientific research and public rhetoric over the decades has confirmed empirically that the oil giant misled the public about what it knew about climate change and the risks posed by fossil fuel emissions, the authors said on Tuesday [August 22, 2017].

[1] Geoffrey Supran and Naomi Oreskes, "Assessing ExxonMobil's climate change communications (1977–2014)" in *Environmental Research Letters*, Vol. 12, no. 8, August 23, 2017. © 2017 The Author(s). Published by IOP Publishing Ltd.

The paper confirms the findings of a 2015 investigative series by InsideClimate News[2] that was based largely on the company's internal records, and also of independent work published by the *Los Angeles Times*. That reporting ignited investigations by state attorneys general that are still in litigation.

"On the question of whether ExxonMobil misled non-scientific audiences about climate science, our analysis supports the conclusion that it did," Geoffrey Supran and Naomi Oreskes of Harvard University wrote in the study, published today in the scientific journal *Environmental Research Letters*.

Across the board, the paper found "a systematic discrepancy between what ExxonMobil's scientists and executives discussed about climate change privately and in academic circles and what it presented to the general public," the authors said.

"ExxonMobil contributed quietly to the science and loudly to raising doubts about it," they wrote.

The authors explicitly rejected Exxon's main defense, which was to claim that journalists were "cherry picking" the company's record and that its positions had always been in step with the state of the science. The company often said that anyone who read the full documentary record would see matters Exxon's way.

The Harvard researchers said their task was to accept Exxon's challenge to review the full record. Among the documents they examined were dozens cited in ICN's work, as well as more than 50 scientific papers Exxon frequently mentioned in its own defense and its issue advertising.

Supran and Oreskes called their conclusions "an expansive, quantitative, independent corroboration of the findings of investigative journalists."

In an interview, Supran said the evidence was unambiguous.

The authors reviewed 187 public and internal Exxon documents over the past four decades, including many that were brought to light by ICN's reporting.

In one finding, they judged that 83 percent of peer-reviewed papers written by company scientists and 80 percent of the company's internal communications acknowledged that climate change is real and caused by humans. But among Exxon's advertisements on the editorial pages of the *New York Times*, a proxy for communications aimed at a broad public audience, only 12 percent acknowledged climate change as real and human-caused, while 81 percent expressed doubt.

[2] Neela Banerjee, Lisa Song, and David Hasemyer, "Exxon: The Road Not Taken," Sept. 16, 2015, https://insideclimatenews.org/content/Exxon-The-Road-Not-Taken.

Among the documents examined were scientific papers, internal company memos, and paid editorial-style advertisements in the *New York Times*. The documents were scored by reviewers in a standard social-science approach known as content analysis, with an aim of evaluating their viewpoints on climate change and quantifying the consistency of Exxon's communications.

Reviewers looked at the company's views of climate change as real, human-caused, serious and solvable.

They also examined a key point that has come up in recent years: whether the company faces a financial risk of stranded assets as policy makers shift world economies away from fossil fuels because their emissions cause global warming.

Their work was supported by Harvard University Faculty Development Funds and by the Rockefeller Family Fund, which has also supported InsideClimate News.

ICN's series in 2015, "Exxon: The Road Not Taken," won an array of journalism prizes and was a finalist for the 2016 Pulitzer Prize for Public Service. It described how Exxon conducted cutting-edge climate research decades ago and how the company then pivoted to the forefront of climate denial, manufacturing doubt about the climate consensus and the dangers that its own scientists had confirmed.

In an interview, Supran said that the company's "pattern of discrepant, misleading climate communication" seems still pertinent today, even though the documents analyzed here dated back many years.

It's not just the dissonance he sees between Exxon's more recent formal endorsement of a carbon tax and the refusal of almost anyone the company supports in Congress to embrace that kind of climate solution.

"The company's apparent acknowledgement of climate science and its implications," he said, "seems dramatically at odds with basically its current business practice."

Supran cited Exxon's push, thwarted by sanctions so far, to drill in Siberia along with the Russian company Rosneft, even though "that oil and gas resource, the largest untapped oil and gas resource left in the entire world, is quantifiably incompatible with holding warming below 2 degrees," the internationally accepted goal.

"In terms of the company's rhetoric and business practices," he concluded, "there is a pattern of discrepancy between what the company says and what the company does."

Exxon, which did not have access in advance to the full paper under terms of a news embargo imposed by the journal publishing it, did not respond to emails on Tuesday requesting comment.

POPE FRANCIS

On Care for Our Common Home, 2015

When Pope Benedict took the unheard-of step of resigning the papacy in 2013 in the wake of scandals about clerical abuse, few thought the cardinals would choose an Argentine with roots among the most desperately poor to take his place. But they did. Jorge Mario Bergoglio, now known as Pope Francis, worked as a janitor and a nightclub bouncer before enrolling in the seminary. As a priest and as a bishop he served the poor of Buenos Aires.

On June 18, 2015, *Time* magazine wrote: "Pope Francis rocked the international community Thursday with the long-anticipated release of his climate encyclical, an authoritative church teaching poised to reshape the international conversation on climate change." Since its release, the 184-page document has indeed broadened the conversation about climate change and challenged the world to act.

As you read the selection, keep in mind the following questions: How does the pope, who took the name Francis after Francis of Assisi, the patron saint of the poor, show that climate change is especially harmful to the poor? How does he relate deterioration of the environment to such essentials of capitalism as private property, private profits, commerce, and markets?

THINKING HISTORICALLY

Keep in mind the following questions as you read the selection: What does the encyclical suggest about the process of change that led to the current situation? What does the Pope ask of individuals?

1. *"LAUDATO SI', mi' Signore"—"Praise be to you, my Lord."* In the words of this beautiful canticle, Saint Francis of Assisi reminds us that our common home is like a sister with whom we share our life and a beautiful mother who opens her arms to embrace us. "Praise be to you, my Lord, through our Sister, Mother Earth, who sustains and governs us, and who produces various fruit with coloured flowers and herbs."

2. This sister now cries out to us because of the harm we have inflicted on her by our irresponsible use and abuse of the goods with which God has endowed her. We have come to see ourselves as her lords and masters, entitled to plunder her at will. The violence present in our hearts, wounded by sin, is also reflected in the symptoms of sickness

Pope Francis, "On Care for Our Common Home." © Copyright—Libreria Editrice Vaticana, http://w2.vatican.va/content/francesco/en/encyclicals/documents/papa-francesco_20150524_enciclica-laudato-si.html.

evident in the soil, in the water, in the air and in all forms of life. This is why the earth herself, burdened and laid waste, is among the most abandoned and maltreated of our poor; she "groans in travail." We have forgotten that we ourselves are dust of the earth; our very bodies are made up of her elements, we breathe her air and we receive life and refreshment from her waters. . . .

Chapter One: What Is Happening to Our Common Home

I. Pollution and Climate Change

Pollution, waste and the throwaway culture

20. Some forms of pollution are part of people's daily experience. Exposure to atmospheric pollutants produces a broad spectrum of health hazards, especially for the poor, and causes millions of premature deaths. People take sick, for example, from breathing high levels of smoke from fuels used in cooking or heating. There is also pollution that affects everyone, caused by transport, industrial fumes, substances which contribute to the acidification of soil and water, fertilizers, insecticides, fungicides, herbicides and agrotoxins in general. Technology, which, linked to business interests, is presented as the only way of solving these problems, in fact proves incapable of seeing the mysterious network of relations between things and so sometimes solves one problem only to create others.

21. Account must also be taken of the pollution produced by residue, including dangerous waste present in different areas. Each year hundreds of millions of tons of waste are generated, much of it non-biodegradable, highly toxic and radioactive, from homes and businesses, from construction and demolition sites, from clinical, electronic and industrial sources. The earth, our home, is beginning to look more and more like an immense pile of filth. In many parts of the planet, the elderly lament that once beautiful landscapes are now covered with rubbish. Industrial waste and chemical products utilized in cities and agricultural areas can lead to bioaccumulation in the organisms of the local population, even when levels of toxins in those places are low. Frequently no measures are taken until after people's health has been irreversibly affected.

22. These problems are closely linked to a throwaway culture which affects the excluded just as it quickly reduces things to rubbish. To cite one example, most of the paper we produce is thrown away and not recycled. It is hard for us to accept that the way natural ecosystems work is exemplary: plants synthesize nutrients which feed herbivores;

these in turn become food for carnivores, which produce significant quantities of organic waste which give rise to new generations of plants. But our industrial system, at the end of its cycle of production and consumption, has not developed the capacity to absorb and reuse waste and by-products. We have not yet managed to adopt a circular model of production capable of preserving resources for present and future generations, while limiting as much as possible the use of non-renewable resources, moderating their consumption, maximizing their efficient use, reusing and recycling them. A serious consideration of this issue would be one way of counteracting the throwaway culture which affects the entire planet, but it must be said that only limited progress has been made in this regard.

Climate as a common good

23. The climate is a common good, belonging to all and meant for all. At the global level, it is a complex system linked to many of the essential conditions for human life. A very solid scientific consensus indicates that we are presently witnessing a disturbing warming of the climatic system. In recent decades this warming has been accompanied by a constant rise in the sea level and, it would appear, by an increase of extreme weather events, even if a scientifically determinable cause cannot be assigned to each particular phenomenon. Humanity is called to recognize the need for changes of lifestyle, production and consumption, in order to combat this warming or at least the human causes which produce or aggravate it. It is true that there are other factors (such as volcanic activity, variations in the earth's orbit and axis, the solar cycle), yet a number of scientific studies indicate that most global warming in recent decades is due to the great concentration of greenhouse gases (carbon dioxide, methane, nitrogen oxides and others) released mainly as a result of human activity. As these gases build up in the atmosphere, they hamper the escape of heat produced by sunlight at the earth's surface. The problem is aggravated by a model of development based on the intensive use of fossil fuels, which is at the heart of the worldwide energy system. Another determining factor has been an increase in changed uses of the soil, principally deforestation for agricultural purposes.

24. Warming has effects on the carbon cycle. It creates a vicious circle which aggravates the situation even more, affecting the availability of essential resources like drinking water, energy and agricultural production in warmer regions, and leading to the extinction of part of the planet's biodiversity. The melting in the polar ice caps and in high altitude plains can lead to the dangerous release of methane gas, while the decomposition of frozen organic material can further increase the emission of carbon dioxide. Things are made worse by the loss of tropical forests which would otherwise help to mitigate climate change.

Carbon dioxide pollution increases the acidification of the oceans and compromises the marine food chain. If present trends continue, this century may well witness extraordinary climate change and an unprecedented destruction of ecosystems, with serious consequences for all of us. A rise in the sea level, for example, can create extremely serious situations, if we consider that a quarter of the world's population lives on the coast or nearby, and that the majority of our megacities are situated in coastal areas. . . .

Chapter Two: The Gospel of Creation

VI. The Common Destination of Goods

93. Whether believers or not, we are agreed today that the earth is essentially a shared inheritance, whose fruits are meant to benefit everyone. For believers, this becomes a question of fidelity to the Creator, since God created the world for everyone. Hence every ecological approach needs to incorporate a social perspective which takes into account the fundamental rights of the poor and the underprivileged. The principle of the subordination of private property to the universal destination of goods, and thus the right of everyone to their use, is a golden rule of social conduct and "the first principle of the whole ethical and social order." The Christian tradition has never recognized the right to private property as absolute or inviolable, and has stressed the social purpose of all forms of private property. Saint John Paul II forcefully reaffirmed this teaching, stating that "God gave the earth to the whole human race for the sustenance of all its members, *without excluding or favouring anyone*." These are strong words. He noted that "a type of development which did not respect and promote human rights — personal and social, economic and political, including the rights of nations and of peoples — would not be really worthy of man." He clearly explained that "the Church does indeed defend the legitimate right to private property, but she also teaches no less clearly that there is always a social mortgage on all private property, in order that goods may serve the general purpose that God gave them." Consequently, he maintained, "it is not in accord with God's plan that this gift be used in such a way that its benefits favour only a few." This calls into serious question the unjust habits of a part of humanity. . . .

Chapter Five: Lines of Approach and Action

IV. Politics and Economy in Dialogue for Human Fulfillment

189. Politics must not be subject to the economy, nor should the economy be subject to the dictates of an efficiency-driven paradigm of technocracy. Today, in view of the common good, there is urgent need

for politics and economics to enter into a frank dialogue in the service of life, especially human life . . .

190. Here too, it should always be kept in mind that "environmental protection cannot be assured solely on the basis of financial calculations of costs and benefits. The environment is one of those goods that cannot be adequately safeguarded or promoted by market forces." Once more, we need to reject a magical conception of the market, which would suggest that problems can be solved simply by an increase in the profits of companies or individuals. Is it realistic to hope that those who are obsessed with maximizing profits will stop to reflect on the environmental damage which they will leave behind for future generations? Where profits alone count, there can be no thinking about the rhythms of nature, its phases of decay and regeneration, or the complexity of ecosystems which may be gravely upset by human intervention. . . .

Chapter Six: Ecological Education and Spirituality

202. Many things have to change course, but it is we human beings above all who need to change. We lack an awareness of our common origin, of our mutual belonging, and of a future to be shared with everyone. This basic awareness would enable the development of new convictions, attitudes and forms of life. A great cultural, spiritual and educational challenge stands before us, and it will demand that we set out on the long path of renewal.

5

NAOMI KLEIN

"How Science Is Telling Us All to Revolt," 2013

Naomi Klein is a Canadian journalist, author, and social activist. This selection introduces the theme of her book, *This Changes Everything: Capitalism vs. the Climate* (2014). As you read the selection, keep in mind the following questions: How are the work and language of the scientists Klein discusses different from that of Pope Francis? How are their conclusions similar? How would you compare their proposed solutions?

THINKING HISTORICALLY

The climate scientists presented by Klein describe the processes of change by plotting precise measurements of things such as carbon, sea level, and temperature at regular intervals. The resulting data give them an accurate history of the processes they're mapping. Normally, scientists, like historians, are content with describing processes. They rarely have the confidence to make predictions, and they almost never engage in extreme political action based on predictions. Klein's scientists do both. Keep in mind the following questions as you read the selection: What do you think accounts for this departure from the typical step-by-step, gradual methods of science? What makes a process of global change so important—and so certain—that extraordinary action on the part of scientists is acceptable? Is climate change such a process? Is capitalism its cause?

Is our relentless quest for economic growth killing the planet? Climate scientists have seen the data—and they are coming to some incendiary conclusions.

In December 2012, a pink-haired complex systems researcher named Brad Werner made his way through the throng of 24,000 earth and space scientists at the Fall Meeting of the American Geophysical Union, held annually in San Francisco. This year's conference had some big-name participants, from Ed Stone of NASA's Voyager project, explaining a new milestone on the path to interstellar space, to the film-maker James Cameron, discussing his adventures in deep-sea submersibles.

But it was Werner's own session that was attracting much of the buzz. It was titled "Is Earth F**ked?" (full title: "Is Earth F**ked? Dynamical Futility of Global Environmental Management and Possibilities for Sustainability via Direct Action Activism").

Standing at the front of the conference room, the geophysicist from the University of California, San Diego walked the crowd through the advanced computer model he was using to answer that question. He talked about system boundaries, perturbations, dissipation, attractors, bifurcations and a whole bunch of other stuff largely incomprehensible to those of us uninitiated in complex systems theory. But the bottom line was clear enough: global capitalism has made the depletion of resources so rapid, convenient and barrier-free that "earth-human systems" are becoming dangerously unstable in response. When pressed by a journalist for a clear answer on the "are we f**ked" question, Werner set the jargon aside and replied, "More or less."

There was one dynamic in the model, however, that offered some hope. Werner termed it "resistance"—movements of "people or groups of people" who "adopt a certain set of dynamics that does

not fit within the capitalist culture." According to the abstract for his presentation, this includes "environmental direct action, resistance taken from outside the dominant culture, as in protests, blockades and sabotage by indigenous peoples, workers, anarchists and other activist groups."

Serious scientific gatherings don't usually feature calls for mass political resistance, much less direct action and sabotage. But then again, Werner wasn't exactly calling for those things. He was merely observing that mass uprisings of people—along the lines of the abolition movement, the civil rights movement or Occupy Wall Street—represent the likeliest source of "friction" to slow down an economic machine that is careening out of control. We know that past social movements have "had tremendous influence on . . . how the dominant culture evolved," he pointed out. So it stands to reason that, "if we're thinking about the future of the earth, and the future of our coupling to the environment, we have to include resistance as part of that dynamics." And that, Werner argued, is not a matter of opinion, but "really a geophysics problem."

Plenty of scientists have been moved by their research findings to take action in the streets. Physicists, astronomers, medical doctors and biologists have been at the forefront of movements against nuclear weapons, nuclear power, war, chemical contamination and creationism. And in November 2012, *Nature* published a commentary by the financier and environmental philanthropist Jeremy Grantham urging scientists to join this tradition and "be arrested if necessary," because climate change "is not only the crisis of your lives—it is also the crisis of our species' existence."

Some scientists need no convincing. The godfather of modern climate science, James Hansen, is a formidable activist, having been arrested some half-dozen times for resisting mountain-top removal coal mining and tar sands pipelines (he even left his job at NASA this year in part to have more time for campaigning). Two years ago, when I was arrested outside the White House at a mass action against the Keystone XL tar sands pipeline, one of the 166 people in cuffs that day was a glaciologist named Jason Box, a world-renowned expert on Greenland's melting ice sheet.

"I couldn't maintain my self-respect if I didn't go," Box said at the time, adding that "just voting doesn't seem to be enough in this case. I need to be a citizen also."

This is laudable, but what Werner is doing with his modelling is different. He isn't saying that his research drove him to take action to stop a particular policy; he is saying that his research shows that our entire economic paradigm is a threat to ecological stability. And indeed that challenging this economic paradigm—through mass-movement counter-pressure—is humanity's best shot at avoiding catastrophe.

That's heavy stuff. But he's not alone. Werner is part of a small but increasingly influential group of scientists whose research into the destabilisation of natural systems—particularly the climate system—is leading them to similarly transformative, even revolutionary, conclusions. And for any closet revolutionary who has ever dreamed of overthrowing the present economic order in favour of one a little less likely to cause Italian pensioners to hang themselves in their homes, this work should be of particular interest. Because it makes the ditching of that cruel system in favour of something new (and perhaps, with lots of work, better) no longer a matter of mere ideological preference but rather one of species-wide existential necessity.

Leading the pack of these new scientific revolutionaries is one of Britain's top climate experts, Kevin Anderson, the deputy director of the Tyndall Centre for Climate Change Research, which has quickly established itself as one of the UK's premier climate research institutions. Addressing everyone from the Department for International Development to Manchester City Council, Anderson has spent more than a decade patiently translating the implications of the latest climate science to politicians, economists and campaigners. In clear and understandable language, he lays out a rigorous road map for emissions reduction, one that provides a decent shot at keeping global temperature rise below 2° Celsius, a target that most governments have determined would stave off catastrophe.

But in recent years Anderson's papers and slide shows have become more alarming. Under titles such as "Climate Change: Going Beyond Dangerous . . . Brutal Numbers and Tenuous Hope," he points out that the chances of staying within anything like safe temperature levels are diminishing fast.

With his colleague Alice Bows, a climate mitigation expert at the Tyndall Centre, Anderson points out that we have lost so much time to political stalling and weak climate policies—all while global consumption (and emissions) ballooned—that we are now facing cuts so drastic that they challenge the fundamental logic of prioritizing GDP growth above all else.

Anderson and Bows inform us that the often-cited long-term mitigation target—an 80 percent emissions cut below 1990 levels by 2050—has been selected purely for reasons of political expediency and has "no scientific basis." That's because climate impacts come not just from what we emit today and tomorrow, but from the cumulative emissions that build up in the atmosphere over time. And they warn that by focusing on targets three and a half decades into the future—rather than on what we can do to cut carbon sharply and immediately—there is a serious risk that we will allow our emissions to continue to soar for years to come, thereby blowing through far too much of our 2° "carbon budget" and putting ourselves in an impossible position later in the century.

Which is why Anderson and Bows argue that, if the governments of developed countries are serious about hitting the agreed upon international target of keeping warming below 2° Celsius, and if reductions are to respect any kind of equity principle (basically that the countries that have been spewing carbon for the better part of two centuries need to cut before the countries where more than a billion people still don't have electricity), then the reductions need to be a lot deeper, and they need to come a lot sooner. . . .

The fact that the business-as-usual pursuit of profits and growth is destabilising life on earth is no longer something we need to read about in scientific journals. The early signs are unfolding before our eyes. And increasing numbers of us are responding accordingly: blockading fracking activity in Balcombe; interfering with Arctic drilling preparations in Russian waters (at tremendous personal cost); taking tar sands operators to court for violating indigenous sovereignty; and countless other acts of resistance large and small. In Brad Werner's computer model, this is the "friction" needed to slow down the forces of destabilisation; the great climate campaigner Bill McKibben calls it the "antibodies" rising up to fight the planet's "spiking fever."

It's not a revolution, but it's a start. And it might just buy us enough time to figure out a way to live on this planet that is distinctly less f**ked.

6

CORAL DAVENPORT

"Major Climate Report Describes a Strong Risk of Crisis as Early as 2040," 2018

Each new study of global warming seems to describe a more serious problem than the last. Rather than exaggerating the problem, each report turns out to be have been too cautious. The latest major report at this writing is the most disturbing yet. As you read the selection, keep in mind the following questions: What do scientists know now that they missed in earlier climate studies? How have their expectations about global warming changed? What new consequences do they foresee in the near and not-so-far future?

THINKING HISTORICALLY

The scientific method is cautious, and scientists are careful not to say more than the evidence allows. They are trained to try to disprove their theories, while many politicians are the opposite. Politicians tend to overpromise and exaggerate, have difficulty seeing past the next election cycle, and are often dependent on private corporate interests to keep their jobs. Keep in mind the following questions as you read the selection: What can and should be done by scientists and politicians to address this crisis? What can we do to support solutions that address the serious problem of climate change?

Incheon, South Korea—A landmark report from the United Nations' scientific panel on climate change paints a far more dire picture of the immediate consequences of climate change than previously thought and says that avoiding the damage requires transforming the world economy at a speed and scale that has "no documented historic precedent."

The report, issued on Monday by the Intergovernmental Panel on Climate Change, a group of scientists convened by the United Nations to guide world leaders, describes a world of worsening food shortages and wildfires, and a mass die-off of coral reefs as soon as 2040—a period well within the lifetime of much of the global population.

The report "is quite a shock, and quite concerning," said Bill Hare, an author of previous I.P.C.C. reports and a physicist with Climate Analytics, a nonprofit organization. "We were not aware of this just a few years ago." The report was the first to be commissioned by world leaders under the Paris agreement, the 2015 pact by nations to fight global warming.

The authors found that if greenhouse gas emissions continue at the current rate, the atmosphere will warm up by as much as 2.7 degrees Fahrenheit (1.5 degrees Celsius) above preindustrial levels by 2040, inundating coastlines and intensifying droughts and poverty. Previous work had focused on estimating the damage if average temperatures were to rise by a larger number, 3.6 degrees Fahrenheit (2 degrees Celsius), because that was the threshold scientists previously considered for the most severe effects of climate change.

The new report, however, shows that many of those effects will come much sooner, at the 2.7-degree mark.

Avoiding the most serious damage requires transforming the world economy within just a few years, said the authors, who estimate that the damage would come at a cost of $54 trillion. But while they conclude that it is technically possible to achieve the rapid changes required to avoid 2.7 degrees of warming, they concede that it may be politically unlikely.

For instance, the report says that heavy taxes or prices on carbon dioxide emissions—perhaps as high as $27,000 per ton by 2100—would be required. But such a move would be almost politically impossible in the United States, the world's largest economy and second-largest greenhouse gas emitter behind China. Lawmakers around the world, including in China, the European Union and California, have enacted carbon pricing programs.

President Trump, who has mocked the science of human-caused climate change, has vowed to increase the burning of coal and said he intends to withdraw from the Paris agreement. And on Sunday in Brazil, the world's seventh-largest emitter of greenhouse gas, voters appeared on track to elect a new president, Jair Bolsonaro, who has said he also plans to withdraw from the accord.

The report was written and edited by 91 scientists from 40 countries who analyzed more than 6,000 scientific studies. The Paris agreement set out to prevent warming of more than 3.6 degrees above preindustrial levels—long considered a threshold for the most severe social and economic damage from climate change. But the heads of small island nations, fearful of rising sea levels, had also asked scientists to examine the effects of 2.7 degrees of warming.

Absent aggressive action, many effects once expected only several decades in the future will arrive by 2040, and at the lower temperature, the report shows. "It's telling us we need to reverse emissions trends and turn the world economy on a dime," said Myles Allen, an Oxford University climate scientist and an author of the report.

To prevent 2.7 degrees of warming, the report said, greenhouse pollution must be reduced by 45 percent from 2010 levels by 2030, and 100 percent by 2050. It also found that, by 2050, use of coal as an electricity source would have to drop from nearly 40 percent today to between 1 and 7 percent. Renewable energy such as wind and solar, which make up about 20 percent of the electricity mix today, would have to increase to as much as 67 percent.

"This report makes it clear: There is no way to mitigate climate change without getting rid of coal," said Drew Shindell, a climate scientist at Duke University and an author of the report.

The World Coal Association disputed the conclusion that stopping global warming calls for an end of coal use. In a statement, Katie Warrick, its interim chief executive, noted that forecasts from the International Energy Agency, a global analysis organization, "continue to see a role for coal for the foreseeable future."

Ms. Warrick said her organization intends to campaign for governments to invest in carbon capture technology. Such technology, which is currently too expensive for commercial use, could allow coal to continue to be widely used.

Despite the controversial policy implications, the United States delegation joined more than 180 countries on Saturday in accepting the report's summary for policymakers, while walking a delicate diplomatic line. A State Department statement said that "acceptance of this report by the panel does not imply endorsement by the United States of the specific findings or underlying contents of the report."

The State Department delegation faced a conundrum. Refusing to approve the document would place the United States at odds with many nations and show it rejecting established academic science on the world stage. However, the delegation also represents a president who has rejected climate science and climate policy.

"We reiterate that the United States intends to withdraw from the Paris agreement at the earliest opportunity absent the identification of terms that are better for the American people," the statement said.

The report attempts to put a price tag on the effects of climate change. The estimated $54 trillion in damage from 2.7 degrees of warming would grow to $69 trillion if the world continues to warm by 3.6 degrees and beyond, the report found, although it does not specify the length of time represented by those costs.

The report concludes that the world is already more than halfway to the 2.7-degree mark. Human activities have caused warming of about 1.8 degrees since about the 1850s, the beginning of large-scale industrial coal burning, the report found.

The United States is not alone in failing to reduce emissions enough to prevent the worst effects of climate change. The report concluded that the greenhouse gas reduction pledges put forth under the Paris agreement will not be enough to avoid 3.6 degrees of warming.

The report emphasizes the potential role of a tax on carbon dioxide emissions. "A price on carbon is central to prompt mitigation," the report concludes. It estimates that to be effective, such a price would have to range from $135 to $5,500 per ton of carbon dioxide pollution in 2030, and from $690 to $27,000 per ton by 2100.

By comparison, under the Obama administration, government economists estimated that an appropriate price on carbon would be in the range of $50 per ton. Under the Trump administration, that figure was lowered to about $7 per ton.

Americans for Prosperity, the political advocacy group funded by the libertarian billionaires Charles and David Koch, has made a point of campaigning against politicians who support a carbon tax.

"Carbon taxes are political poison because they increase gas prices and electric rates," said Myron Ebell, who heads the energy program at the Competitive Enterprise Institute, an industry-funded Washington research organization, and who led the Trump administration's transition at the Environmental Protection Agency.

The report details the economic damage expected should governments fail to enact policies to reduce emissions. The United States, it said, could lose roughly 1.2 percent of gross domestic product for every 1.8 degrees of warming.

In addition, it said, the United States along with Bangladesh, China, Egypt, India, Indonesia, Japan, the Philippines and Vietnam are home to 50 million people who will be exposed to the effects of increased coastal flooding by 2040, if 2.7 degrees of warming occur.

At 3.6 degrees of warming, the report predicts a "disproportionately rapid evacuation" of people from the tropics. "In some parts of the world, national borders will become irrelevant," said Aromar Revi, director of the Indian Institute for Human Settlements and an author of the report. "You can set up a wall to try to contain 10,000 and 20,000 and one million people, but not 10 million."

The report also finds that, in the likelihood that governments fail to avert 2.7 degrees of warming, another scenario is possible: The world could overshoot that target, heat up by more than 3.6 degrees, and then through a combination of lowering emissions and deploying carbon capture technology, bring the temperature back down below the 2.7-degree threshold.

In that scenario, some damage would be irreversible, the report found. All coral reefs would die. However, the sea ice that would disappear in the hotter scenario would return once temperatures had cooled off.

"For governments, the idea of overshooting the target but then coming back to it is attractive because then they don't have to make such rapid changes," Dr. Shindell said. "But it has a lot of disadvantages."

■ REFLECTIONS

Solving global warming begins with a recognition of its importance, which has been made all the more difficult by a number of problems related to its huge scale. First, its slowness: in an age of micro attention spans, a one- or two-degree-per-century change in global climate is difficult to understand and appreciate, much less raise an alarm. Second, its inertia: even if atmospheric carbon is limited to today's approximately 2 percent, its effects will persist for tens of thousands of years. Third, its effects do not remain the same: they escalate in vicious circles of warming air, melting ice, and warming oceans releasing more carbon, increasing warming.

The already baked-in damage that will occur is hidden by our human-time horizons. As the oceans rise, the grains of sand that are washed away can be replenished, the homes that are flooded can be raised, the sea walls can be built higher—at least in wealthy first-world

beachfront communities. But the eventual cost of evacuating tens or even hundreds of millions from coastal cities, swollen deltas, and island nations is overwhelming.

Global warming is the leading edge of many other climate changes that follow in its wake. The warming of the earth's atmosphere concentrates precipitation in some areas, especially near the equator, while it extends areas of dry air into the middle latitudes. The result is the expansion of deserts in the Sahara, central Asia, Mexico, Central America, and the southwest U.S., increased droughts and crop failure in already dry farm land, and increased winds and fires across the northern hemisphere agricultural and forest belts. A similar drying out over the lesser land in the southern hemisphere still includes much of southern Africa, Australia, and South America. At the same time, increased rainfall in the polar regions and lower latitudes threatens the equatorial belt through East Africa, southern India, Southeast Asia, Southern China, and across the Pacific to the west coast of the Americas. The resulting disruption of crops, species, and human lives is incalculable. Hundreds of millions, if not billions, of people would be uprooted and become refugees.

These are problems on a scale the world has never seen, not even in the bleakest days of twentieth-century world war. The institutions of national and international government seem poorly equipped to address anything beyond short-term horizons. The vaunted technology of industrialization cannot be expected to solve the problem it caused. And an economic system based on ever-increasing consumption and the private exploitation of the world's resources lacks the tools or the will to steer a different course.

So what is to be done? And what can the individual do? Often calls for change echo between those who want to change souls and those who want to change things. One might expect the pleas of Pope Francis and Naomi Klein to bounce off each other in that way. But in fact they do not. Their language is different, but their agreement on the message may be a hopeful sign. But the clock is ticking.