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# Resilient Decarbonization for the United States: Lessons for Electric Systems from a Decade of Extreme Weather

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Lessons for electric systems from a decade of extreme weather

by

Sohum Pawar

A.B. Environmental Science and Public Policy, and Engineering Sciences
Harvard University (2018)

Submitted to the Institute for Data, Systems, and Society
in partial fulfillment of the requirements for the degree of

Master of Science in Technology and Policy

at the

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## Abstract

The past decade has seen an unprecedented surge of climate change-driven extreme weather events that have wrought over $800 billion in damage and taken more than 5,200 lives across the United States — a trend that appears poised to intensify. At the same time, the need for a large-scale effort to decarbonize the U.S. electric power system has become clear, along with the growing climate risks and impacts that any such effort will face.

This thesis argues that the principles of resilience can play a valuable role by enabling the decarbonization of the U.S. electric system, in the face of the escalating risks and impacts of climate-driven extreme weather.

By emphasizing targeted hardening, proactive planning, graceful failure, and effective recoveries in the design, operation, and oversight of electric systems in the United States, we can both protect against growing climate risks and catalyze decarbonization efforts — an integrated process we call resilient decarbonization.

This work seeks to inform present and future resilient decarbonization efforts by examining the lessons of the past decade of extreme weather, and its impact on electric systems in the United States. To do so, we consider three cases: Hurricane Maria, which struck Puerto Rico in 2017, causing the world's second-largest blackout; the 2017-2019 Northern California wildfire seasons, which sent the nation's largest investor-owned-utility into bankruptcy and remain the most devastating on record; and Superstorm Sandy, which served as a wakeup call for the New York/New Jersey area when it made a sudden left turn towards the region in 2012.

We find that resilient decarbonization, while a challenging process to set into motion, does in fact meet its dual mission of protecting electric systems against growing climate risks, while enabling their decarbonization. We also examine the ways in which electric system institutions take climate risks into account, the strengths and weaknesses of resilience-based measures for electric systems, and overarching questions about the role of electricity and electric utilities in American society today.

Thesis Supervisor: Michael J. Kearney
Title: Executive Director, The Roosevelt Project

# Acknowledgements

I'll be the first to admit that the MIT firehose and I have become well-acquainted over the past two years. My time here has been yet another rollercoaster, and a humbling experience. But as I close out six years in Cambridge, I'm incredibly grateful for the incredible opportunities I've been given — and I'm determined to pay them forward by being of public service, and trying to do some good.

This thesis wouldn't have been possible without the guidance and support of Dr. Mike Kearney. Mike gave me a fresh chance to dive back into the policy world, while also entrusting me with the freedom to explore all of my academic passions. He helped corral my raw excitement into finished research, and offered me infinite patience and a firm nudge when I needed them most — all while encouraging me to keep my eyes on the bigger picture. Thank you, for a fantastic year.

For the past two years, the Technology and Policy Program has been the perfect home for an excitable, optimistic nerd like me. My gratitude to Barb DeLaBarre, for her open door and endless supply of chocolate; Frank Field, for his timely advice; and Prof. Noelle Selin, for an initial nudge towards TPP, all those years ago.

I'm also grateful to have had the chance to work alongside the amazing team behind the Roosevelt Project, led by Secretary Ernie Moniz, and to be a part of the vibrant research communities in CEEPR and MITEI.

A special thanks to the remarkable teams at the Prime Coalition and FireEye, who helped reignite my belief that the climate fight is one that we have the power to win, and gave me a unique look into what it takes to protect the systems that power our society.

My time at MIT would not have been the same without an incredible group of friends, old and new, who have been by my side through the highest highs and lowest lows. Thank you for the four-hour debates and endless group chat dialectics, the runs along the Charles and late nights spent staring at the stars, and the countless ice cream trips. More than any class or assignment, you've challenged and shaped the way I look at the world — all while making me laugh harder than I knew was possible.

My parents and Anokhi didn't bat an eye when I told them that I was going to be writing my second thesis in two years, and gave me the encouragement I needed to get it done. The seeds of this thesis were planted in 2011, as we huddled together without power in our home while Hurricane Irene battered New Jersey. Since then, they've indulged more of my musing questions, historical fun facts, and excited tangents than anyone can count. They've been my biggest supporters, and the fact that I'm about to move to Washington, D.C. to pursue my dreams simply wouldn't have been possible without them.

And finally, this thesis is dedicated to the victims of Superstorm Sandy, Hurricane Maria, and the California wildfires. Their stories and sacrifices offer us a timely lesson, a sobering warning, and an optimistic call to action: though climate change will have terrible, human costs, the power to prevent the worst of its impacts is still in our hands.

The origins of this thesis.

East Hanover, New Jersey
October 29, 2011

Hurricane Irene

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# 1 Introduction

At the outset, the 2010s seemed to hold great promise for the United States. A dynamic, newly-elected president promised to lead us out of the worst financial crisis since the Great Depression and into a bright new future — a future powered by a cleaner, smarter electrical system, that would drive America's fight against the generational challenge of climate change. And while the decade saw the longest economic expansion in the nation's history, lasting an unprecedented 129 weeks from June 2009 through March 2020,[1] our progress on the climate and decarbonization front over its span can best be characterized as "two steps forward, one leap back."

But while elected officials, private companies, and the American public marked the decade with sparring matches over any number of climate and decarbonization issues, nature was marking it with a different set of milestones: a series of record-shattering extreme weather events. The decade from 2010 through 2019 saw extreme weather cause more damage in the United States than any other on record — with 119 disaster events that caused a total of more than $800 billion in damage and claimed over 5,200 lives.[2]

Along the way, these disasters burned their names into our national consciousness: Superstorm Sandy, Hurricane Maria, the Camp Fire. Each was a devastating tragedy in its own right, but together, they are the harbingers of that generational challenge: a predicted increase in the risks of climate-driven extreme weather, as well as its impacts across the United States.

As a nation, we have come to recognize that any serious effort to fight climate change will require dramatically cutting our greenhouse gas emissions. A key component of that effort will be the decarbonization of our electric system — the pulsing heart and arteries that power nearly every aspect of modern American society.

However, we have also come to recognize that decarbonization will require a massive buildout of electric system infrastructure — an expansion that will almost certainly occur in harm's way. This build out will take place in communities across the country, many of which are already the among the most vulnerable to the very same risks of extreme weather that are being exacerbated by climate change.

[1] U.S. Bureau of Economic Analysis, "GDP."
[2] Smith and National Centers for Environmental Information, "2010-2019: A Landmark Decade of U.S. Billion-Dollar Weather and Climate Disasters."

This thesis will argue that the principles of resilience can play a valuable role by enabling the decarbonization of the U.S. electric system, in the face of the escalating risks and impacts of climate-driven extreme weather — a concept we call resilient decarbonization.

To do so, we will consider what lessons the last decade of extreme weather can offer us about what resilient decarbonization might look like for the U.S. electric system. We will begin by setting out the three pillars upon which this thesis rests: the need for decarbonization of the U.S. electric system, the climate risks and impacts facing the U.S., and the potential for a resilience-centric approach to decarbonization. Having established this conceptual and empirical foundation, we will then examine three case studies drawn from the past decade of extreme weather events in the United States. In each case, we will seek to identify both bright spots and cautionary tales — lessons that we can extract, which might help inform and enable resilient decarbonization.

First, we will consider Hurricane Maria, which blazed a path across Puerto Rico in September 2017. In its wake, Maria would leave nearly 3,000 dead, completely destroying the Puerto Rican electric system and causing the second largest power outage the world has ever seen. We will examine how a legacy of legal loopholes, financial missteps, and the systematic second-class status accorded to U.S. territories weakened the commonwealth's institutions. We will also examine the series of events that led up to the blackout, and follow the island's slow, halting recovery. In the aftermath of the crisis, we will examine the efforts that have been made to increase the electric system's resilience against future Maria-caliber storms. And we will examine how those efforts fared in the face of the first major test of Puerto Rico's electric system resilience: a series of earthquakes that rattled the island.

Next, we will examine the 2017 and 2018 Northern California wildfire seasons, and the Camp Fire — the deadliest wildfire in California history. We'll begin by following the stories of the two most destructive wildfire seasons the state has ever seen, before diving into the story of the Camp Fire, and the events that precipitated it. We'll consider how an increase in climate-driven wildfire risk has threatened, and continues to threaten Northern California, before turning to the other key figures in these fires: the Pacific Gas and Electric Company, whose electrical equipment caused eighteen of the most destructive fires over the past three years, and the regulators charged with overseeing them. We'll chronicle the stories of PG&E, its regulators, and their slow-off-the-mark effort to battle an unprecedented surge of flame. We'll then turn our eyes to PG&E's subsequent bankruptcy, and the unique legal liability doctrines that drove it, before considering the remarkable resilience efforts and liability reduction programs that have been put in place since the Camp Fire. Finally, we'll consider how PG&E and its electric system fared in the face of the first major test of their resilience: the 2019 California wildfire season.

Third, we will return to 2012, when Superstorm Sandy made an unexpected left turn towards New York and New Jersey. After examining the events of the storm, its impact on the two states' electrical systems, and the subsequent recovery efforts, we'll consider the climate-driven strengthening of Atlantic hurricanes that Sandy foreshadows. Looking beyond the storm, we'll examine how the aftermath of the storm served as a catalyst for a remarkable, regionwide push for resilient decarbonization — one that could serve as a national model in the years to come.

Having considered these three cases, we'll then synthesize twelve cross-cutting lessons for the resilient decarbonization of the U.S. electric system — categorized by what they tell us about the role of risk, the role of resilience, and value of efforts to reimagine our electric system.

# 2 Foundation: decarbonization, climate risk, & resilience

The foundation of this thesis rests upon three conceptual pillars: decarbonization, climate risk, and resilience. Together, they inform the principle of resilient decarbonization that we see to examine here.

To begin with, we will consider the need to decarbonize (eliminate the production of greenhouse gases from) the U.S. electric system, and estimate the scale of energy infrastructure buildout that an effort to do so would require.

Second, we will evaluate the growing climate risks facing the United States, as well as their impacts on our electric system. We will also examine the particular challenges that climate-driven extreme weather events pose to the U.S. and our electric system.

And finally, we will introduce the concept of resilience — the proactive, risk-informed design of systems that can gracefully fail in the face of overwhelming impacts, in order to minimize damage and facilitate an effective recovery. We will then consider the importance of climate resilience in electric systems, before tying this chapter together by articulating the core ideas that define resilient decarbonization.

## 2.1 Pathways for decarbonizing the U.S. electric system

In this section, we will examine the state of the U.S. electric system, and its role in addressing the challenge of climate change. After noting the progress that has already been made towards decarbonizing the electric system, we'll consider the substantial progress that still remains on its path towards decarbonization. Taking all this into account, we'll then examine what an effort to decarbonize the electric system might actually look like in practice — as well as the infrastructure buildout it will likely require.

### 2.1.1 State of the U.S. electric system

Often referred to as "the largest machine on Earth," the U.S. electrical system forms the backbone of modern American society. Physically, it comprises over 600,000 miles of transmission lines, 5.5 million miles of distribution lines, and more than 8,000 utility-scale generators and 75,000 substations. It supplies more than $375 billion worth of electricity each year — in addition to powering nearly every other sector of the economy.[3,4] Societally, millions of Americans depend on it every day for services ranging from lifesaving medical care to the Internet. And politically, it remains a perpetual flashpoint.

But what we commonly refer to as "the grid" is no monolithic structure. Physically, "the grid" is actually three largely separate electric systems (interconnections), and operationally, it consists of 66 balancing authorities that together manage the flow of electricity across the entire continental United States. The non-contiguous regions of the U.S. (notably Alaska, and Puerto Rico) also have their own, largely "islanded" electric systems.

The electric system begins with its generators, which today can range from a 5 kW photovoltaic installation on the roof of a residential home, to a massive 1.3 GW nuclear power plant. The overwhelming majority of electricity in the U.S. is still generated at centralized, utility-scale generating facilities. Natural gas, coal, uranium, wind, running water, and sunlight combust, react, push, and excite turbines, semiconductors, and motors — generating electricity.

At utility-scale plants, transformers raise that electricity produced by generators to a higher voltage that's more suitable for long distance transmission. High-voltage current is carried from the generation plant by transmission lines, until it reaches an area that's home to consumers — loads, in electrical parlance. There, it is "stepped down" to a lower voltage, more suitable for local distribution, by another set of transformers. Lower-voltage distribution lines carry the electricity to distribution transformers — the metal cylinders commonly seen mounted on electric poles — which then lower the voltage further, to the levels used by everything from refrigerators to computers. It's important to remember that electricity, while often compared to water, doesn't quite flow — it goes where it wants to, almost instantaneously in our perception.[5] As a result, balance is incredibly important to the electric power system.

So, what does the U.S. electric system look like today?

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[3] Marston, "The US Electric Power System Infrastructure and Its Vulnerabilities."

[4] National Academy of Sciences, National Academy of Engineering, and National Research Council, *America's Energy Future*, chap. 9, p.564.

[5] By way of illustration, the chain of failures leading to the 2003 Northeast blackout involved a power swing of 5.7 GW, which that created a cascade of disruptions that left 50 million people without power.

The U.S. has a total generating capacity of 1,100 GW (or 1.1 TW).[6,7] Each year, we consume 4.118 billion kWh of electricity.[8] That electricity is generated by a mix that still remains largely dependent on carbon-emitting fossil fuels, which make up 62.7% of total generation. Natural gas is responsible for 38.4% of U.S. electricity, followed by coal (23.5%). There is also a small fraction of total generation (<1%) that relies on petroleum — on a national scale, this is largely insignificant, but as we will see when we consider the case of Puerto Rico, it can be hugely important in certain regional contexts.

The remaining 37.3% of electricity generation comes from what will call low-carbon energy sources. The largest source of emissions-free energy in the U.S. is nuclear fission, which makes up 19.7% of generation. It is followed by wind power (7.3%), hydropower (6.6%), solar power (1.8%), biomass power (1.4%), and geothermal power (0.5%).

While the carbon-intensive/low-carbon categorization is the most directly pertinent to the question of decarbonization, there's another that comes into play when considering how these generation sources can actually be integrated into the electrical system: variability vs. firmness, as described by Sepulveda, et al. (2018).[9]

Battery storage, demand response, and energy efficiency all play notable — though not yet sizable roles — in our electric system. Battery storage offers an opportunity to increase the firmness of many of the aforementioned variable low-carbon generation technologies (particularly solar). Meanwhile, demand response and energy efficiency measures offer the tantalizing potential of "negawatts" — the ability to reduce electricity demand overall (efficiency), or to use a combination of financially-incentivized contracting and advanced control systems to selectively shift the timing of certain loads (like the charging of an electric car, or the operations of a particular industrial facility), in order to reduce peak electricity demand and better utilize variable generation.

It is important to note that while decarbonizing generation will be the heart of any effort to decarbonize the U.S. electric system, that decarbonization will not be possible without a robust transmission and distribution infrastructure to support it. As we'll discuss

[6] U.S. Energy Information Administration, "Electricity Generation, Capacity, and Sales in the United States."

[7] For context, 1 GW of power is roughly enough to supply 770,000 average American homes.

[8] U.S. Energy Information Administration, "Frequently Asked Questions (FAQs) - What Is U.S. Electricity Generation by Energy Source?"

[9] Sepulveda et al., "The Role of Firm Low-Carbon Electricity Resources in Deep Decarbonization of Power Generation."

in Chapter 2.1.2, regardless of what pathways towards decarbonization we choose, our existing transmission and distribution infrastructure — while, on the whole, finely-tuned and reliable — is insufficiently equipped for the task.

### 2.1.2 Pathways to a decarbonized electric system

Before we talk about what a decarbonized electric system might look like, or how we could build one, we must first establish just how much decarbonization is required.

In 2014, the United Nations' Intergovernmental Panel on Climate Change (IPCC) laid out a clear target for global action. In its Fifth Assessment Report, the IPCC contended that staving off the worst impacts of climate change would require — at minimum —holding the increase in global average temperature to 2ºC over the course of the century.[10] A year later, all 195 UN member and observer nations signed the Paris Agreement, which set the 2ºC target as its primarily goal.[11] As part of the Paris process, the United States laid out its intentions to reduce its emissions by 80% below 2005 levels, by 2050.[12]

However, in the intervening four years, a scientific and policy consensus has emerged that the 2ºC target and the U.S. "80 by 50" targets will likely prove insufficient to truly stave off the worst impacts of climate change on the world's most vulnerable populations. Instead, a consensus has emerged around a lower target of holding average global temperature increase to no more than 1.5ºC over the course of the century. This target has been most prominently articulated by the IPCC's 2018 *Special Report on Global Warming of 1.5ºC*,[13] but was also expressed as the "aspirational" target of the Paris Agreement. From the U.S. perspective, this would require the nation to reach net-zero emissions by or before 2050.

What do these targets mean for the U.S. electric system? The original U.S. Mid-Century Strategy for Deep Decarbonization, submitted to the IPCC in November 2016, called for decarbonizing 92% of our electric system by 2050, in order to meet the 2ºC target.[14] A May 2019 study conducted by the Center for Climate and Energy Solutions, in partnership with the RAND Corporation and Pacific Northwest National Laboratory, found that meeting the

[10] Intergovernmental Panel on Climate Change, "Climate Change 2014: Synthesis Report - Summary for Policymakers."
[11] United Nations Framework Convention on Climate Change, Paris Agreement.
[12] The White House, "United States Mid-Century Strategy for Deep Decarbonization."
[13] Intergovernmental Panel on Climate Change, "Special Report on Global Warming of 1.5ºC - Summary for Policymakers."
[14] The White House, "United States Mid-Century Strategy for Deep Decarbonization," 34.

2°C goal would require the U.S to add roughly 2 terawatts of low-carbon generation capacity by 2050. A study released the same month by the U.S. Deep Decarbonization Pathways Project (DDPP) concurred in this assessment, adding that all scenarios it modeled that met the more stringent 1.5°C target required between 2 and 3 terawatts of additional low carbon generation capacity.[15]

It's important to note that these are all *extremely* aspirational targets. For context, remember that the U.S. electric system today has a total generation capacity of just over 1.1 terawatts. Both studies attribute this massive surge in capacity requirements to the need to support massive, economy-wide electrification efforts (particularly in the transportation sector), and account for the capacity factors of variable low-carbon generation sources. The DDPP study found that meeting the 1.5°C target would require, on average, a tripling of the fraction of final energy use in the United States that goes to electricity usage — from an expected 20% in 2020, to nearly 60% by 2050.[16] That's in addition to the significant expansions of transmission and distribution capacity needed to support the expansion in generation — not to mention a paradigm-shifting expansion in carbon capture and storage capacity, which features prominently in many of the modeled scenarios.

To offer a "worst case" scenario to contract with these aggressive scenarios, we calculated what a "sluggish" decarbonization transition would look like, as part of forthcoming work from the Roosevelt Project at MIT. In that case, we assumed that U.S. decarbonization efforts will either remain at the current rate, or slow down. This would result in emissions continuing to decline at the current (relatively slow) pace of less than one percent per year. Given that U.S. emissions were at 1.3% above 1990 levels as of 2017,[17] this means that under the most generous interpretation, the U.S. would not achieve an 80% emissions reduction until 2098, and net-zero emissions until 2118.

That estimate came in the wake of three years of unprecedented rollbacks of U.S. climate and clean energy policy under the administration of President Donald Trump, and therefore made extremely pessimistic assumptions about U.S. capability to accelerate decarbonization. However, it nevertheless assumed that net-zero decarbonization would occur — necessitating the same, 2 TW-scale buildout of low-carbon generation capacity.

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[15] Haley et al., "350 PPM Pathways for the United States," 40.
[16] Haley et al., 10.
[17] U.S. Environmental Protection Agency, "Inventory of U.S. Greenhouse Gas Emissions and Sinks: 1990-2017."

Therefore, it is this 2 TW figure — a tripling of capacity — that we will focus on when it comes to considering the absolute scale of the needed expansion of the U.S. electric system, over the coming three decades. What will the transition to this expanded, decarbonized electrical system look like?

Well, it's already underway.

From 2005 to 2019, carbon dioxide emissions from the U.S. electric system have fallen by 33% — exceeding the targets set by the Obama Administration under its Clean Power Plan and incorporated into the Mid-Century Strategy.[18,19]

Over that same time period, the percentage of U.S. electricity generated from fossil fuels has fallen from 71.7% to 62.5% — a shift of just over nine percentage points to low-carbon generation sources.

The juxtaposition of these two statistics reveals that a significant fraction of the reduction in electric system carbon emissions thus far has come from fuel switching: the phase-out of coal in favor of natural gas. Since 2005, coal's share of U.S. electricity generation has been more than cut in half — it accounted for nearly 49% of electricity generated in 2005, and only 23.5% of generation in 2019. At the same time, natural gas, which emits roughly half the $CO_2$ of coal when combusted,[20] has more than doubled its share of generation, going from 18.8% of generation in 2005 to 38.4% in 2019, to become the nation's largest source of electricity. This surge has largely been driven by a steep reduction in the price of natural gas, as a result of a massive expansion of U.S. domestic natural gas production enabled by fracking technologies.[21]

That's not to say that low-carbon energy sources haven't made much progress over the past decade and a half. Generation from variable renewables (primarily wind and solar) has increased fivefold since 2005, from 2.2% to 10.9% in 2019 — truly explosive growth. That growth has already begin to realign the U.S. electric generation mix: wind energy has passed hydropower as the leading source of renewable generation, beginning in 2019.[22] Along with the 19.7% of generation that comes from nuclear power and the 6.7% from large-scale

[18] U.S. Energy Information Administration, "Table 11.6 - Carbon Dioxide Emissions From Energy Consumption: Electric Power Sector."
[19] U.S. Environmental Protection Agency, "Fact Sheet: Overview of the Clean Power Plan."
[20] Center for Corporate Climate Leadership, "Emission Factors for Greenhouse Gas Inventories."
[21] Gold, *The Boom: How Fracking Ignited the American Energy Revolution and Changed the World*.
[22] U.S. Energy Information Administration, "Wind Has Surpassed Hydro as Most-Used Renewable Electricity Generation Source in U.S."

hydroelectric power, this means that just under two-fifths of U.S. electricity is generated without producing meaningful carbon emissions.[23]

Given the progress we've already made, where do the trendlines lead us? Coal appears, for all intents and purposes, to be on its way to dying out in the United States. In mid-April 2020, the Georgia Environmental Protection Division denied a permit for a proposed 850 MW coal plant — leaving the U.S. with no proposals for new coal plant construction, for the first time in decades.[24] And while natural gas has been a key driver of the last decade and a half of emissions reduction in the power sector, the fact remains that natural gas is itself a significant source of $CO_2$ emissions. Looking to the future, natural gas will likely have to be paired with carbon capture technologies, to achieve net-zero emissions generation, or else it could follow coal's path to obsolescence within 20-30 years.[25] Similarly, it remains to be seen whether variable renewables like wind and solar will continue their exponential growth rates in the decades to come — and what role the energy storage technologies now being to see wider-scale adoption (like utility-scale battery storage) will play in enabling their adoption.

What appears clear, though, is that U.S. electric system decarbonization on the scale we are considering here — 2 TW of added low-carbon generation, 90-100% reductions in emissions — will raise a whole new set of challenges. Jenkins, et al. (2018) explore this challenge in depth, noting that "reaching near-zero emissions is much more challenging — and requires a different set of low-carbon resources — than comparatively modest emissions reductions." They attribute the bulk of this difficulty to the fact that, as we have discussed, "pushing to near-zero emissions requires replacing the vast majority of fossil fueled power plants or equipping them with CCS."[26]

Jenkins, at al. argue that this challenge becomes even harder if variable renewables are made to carry the burden of decarbonization alone, as their variable generation profiles would require significant storage capability (including long duration storage, which is virtually nonexistent today), substantial transmission expansion, further reductions in wind and solar cost, and more granular control over demand profiles than we have today.

[23] U.S. Energy Information Administration, "Net Generation for All Sectors, Annual (Thousand MWh)."
[24] Sierra Club, "Nation's Last New Coal Plant Proposal Denied in Georgia."
[25] Tsafos, "How Will Natural Gas Fare in the Energy Transition?"
[26] Jenkins, Luke, and Thernstrom, "Getting to Zero Carbon Emissions in the Electric Power Sector."

As an alternative, they argue for what might once have been called an "all-of-the-above" mix of both variable renewables and firm low-carbon energy sources, such as nuclear power, biomass combustion, geothermal energy, and fossil-fueled plants achieving net-zero emissions using CCS. The authors make a persuasive argument that, given the amount of interconnected technical, economic, and policy uncertainty that surrounds decarbonization pathways, all low-carbon options should be on the table for consideration.

Thus far, we have seen that a pathway towards decarbonizing the U.S. electric system will require a substantial expansion of low-carbon generation (on the order of 2 TW), and will likely involve a mix of both variable renewables and firm low-carbon technologies. One final consideration is the role that the geography of low-carbon energy resources in the U.S., and the transmission infrastructure necessary to link those resources to major population/load centers, will have on a decarbonization effort.

One of the key commonalities of the decarbonization pathways surveyed here is the need for an expansion of U.S. transmission infrastructure. Jenkins et al. (2018) cite prior work by the National Renewable Energy Laboratory (NREL) that proposes increases of anywhere from 50-105% in transmission capacity.

The Interconnections Seams Study, a separate, ongoing research project at NREL, has released preliminary results indicating that even in the absence of climate-driven energy policy (such as a carbon price), or transformative generation changes (like the ones we discuss here), there are substantial cost-saving and operational efficiencies that come from expanding U.S. transmission capacity. It particularly focuses on efforts to increase transmission links between the three major U.S. electrical interconnections: the Eastern Interconnection, Western Interconnection, and the Electricity Reliability Council of Texas (ERCOT).

The study first shows that there are cost-savings and system efficiency gains to be realized just from expanding conventional (AC) transmission capacity within each of the interconnections. It then moves on to propose cross-interconnection transmission expansions — high voltage direct current (HVDC) lines that bridge the three asynchronous electric systems, expanding the capability for trans-continental power balancing. Once again in the absence of transformative policy or generation shifts, NREL estimates that the gains from such a cross-interconnection expansion could be on the order of billions of dollars.[27] Perhaps

[27] Bloom and National Renewable Energy Laboratory, "Interconnections Seam Study."

more importantly, it could also be a significant step towards enabling greater penetration of low-carbon generation sources, and thus, towards decarbonization.

The NREL study serves to further underscore the fact that a buildout of transmission capacity will play a significant role in any effort to decarbonize the U.S. electric system.

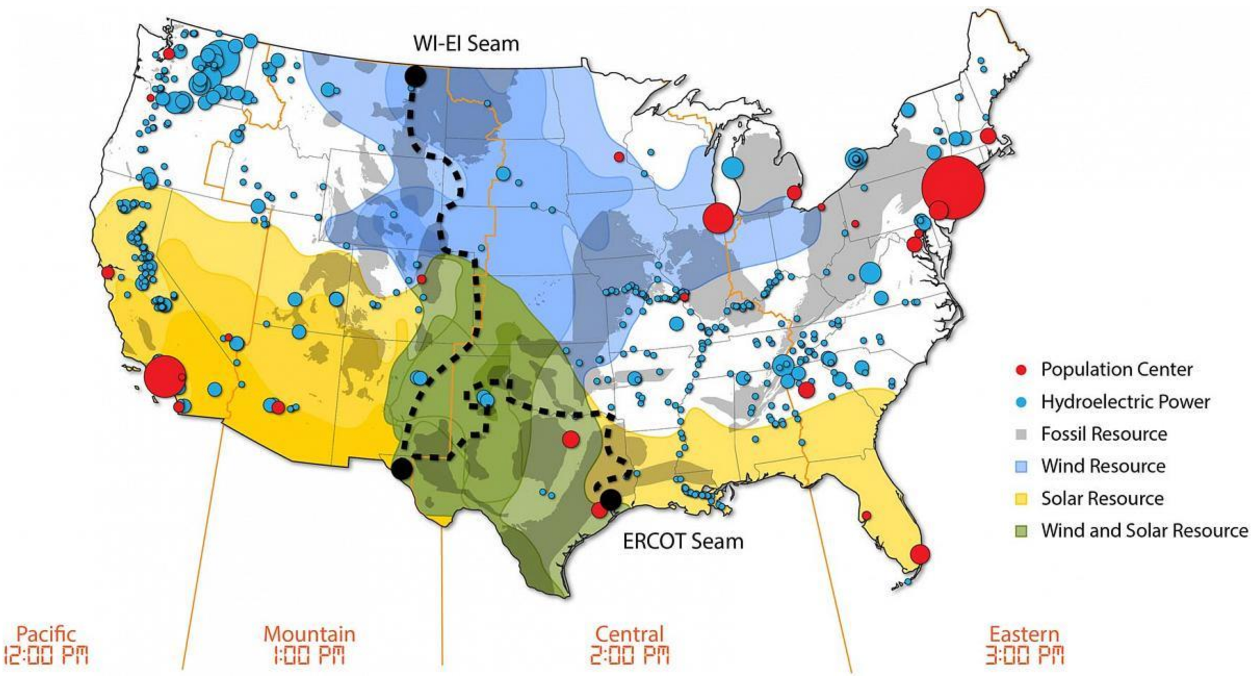


Figure 1. U.S. electric system interconnections, with energy resource regions and major population/load centers overlaid[28]

Finally, but perhaps most importantly, the NREL study also highlights a key observation: the decarbonization of the U.S. electric system will happen… everywhere. As we see in Figure 1, the primary low-carbon resources in the U.S. (areas of high-quality wind and reliable solar irradiance) span a vast geographic range — from coast to coast and from the Great Lakes to the Rio Grande. Meanwhile, existing fossil resources (coalfields and oil/gas basins) and hydroelectric resources (dams with large impoundments) are also distributed across the country. And, most importantly, the U.S.'s population and electric load centers are distributed quite asymmetrically — and, for the most part, a decent distance away from some of the most promising low-carbon resources. Thus, it is completely reasonable to imagine

[28] Bloom and National Renewable Energy Laboratory.

efforts to transmit abundant wind energy from the Great Plains to Chicago, the Industrial Heartland, and perhaps even the mid-Atlantic and the Northeast. Similarly, efforts to use abundant solar resources in Nevada and Arizona to power the massive cities and suburbs of Northern and Southern California seem quite plausible.

This is the thread that pulls our picture of the pathways to decarbonization together: they will require massive scale, a diverse array of low-carbon resources, and be geographically expansive.

### 2.1.3 Key takeaways on decarbonization

The need to decarbonize the U.S. electric system is the first of the three foundational arguments upon which this thesis rests. We have examined the current state of our electrical system, and the progress that has been made towards decarbonization thus far. We then considered the massive scale of low-carbon energy buildout (~2 TW) that a decarbonization effort might require, as well as the diversity of low-carbon resources that will likely need to be deployed in its service. And we considered the significant buildout of transmission capacity that will likely accompany such an effort. It will take place across the country — in every power plant, on every wind-swept plain or sun-kissed desert, and along the winding corridors of transmission lines that crisscross the continent to connect supply and demand.

Taken together, these observations impress upon us one key fact: any effort to fully decarbonize the U.S. electric system will likely be an immense undertaking — in terms of money invested, the time required, the geographic scope involved, and especially the amount of infrastructure that will have to be built anew.

Having assembled a coherent vision of what the massive project of decarbonizing the U.S. electric system might look like, we now turn to a different question: what risks might this expanded, decarbonized new power system face from climate change — the very threat it is intended to mitigate?

## 2.2 Climate risks and impacts on the United States

In April 2013, President Barack Obama told the crowd of students assembled before him at Georgetown University that he "refuse[d] to condemn your generation and future generations to a planet that's beyond fixing."[29] The bold pledge came during the announcement of his Climate Action Plan — an administration-wide push to put climate change and clean energy at the center of the federal government's agenda, from the start of his second term in office.

His focus — on ensuring that the impacts of carbon emissions don't cause irreparable, long-term damage to the Earth's climate and to all of us who depend on its stability — marked the beginning of a four-year push for climate and clean energy policy that included the first-ever domestic regulation of greenhouse gas emissions from the electric sector and a diplomatic effort to secure adoption of the Paris Agreement, among countless others.

However, Obama also recognized that he was speaking just six months after Hurricane Sandy ravaged New York and New Jersey, leaving millions without electricity for days — clear evidence that the impacts of climate change were not just distant, looming dangers.

"What we've learned from Hurricane Sandy and other disasters," the President asserted, "is that we've got to build smarter, more resilient infrastructure that can protect our homes and businesses, and withstand more powerful storms."

As we will observe in Chapter 3, that statement rings truer than ever today. This thesis is aimed at the intersection of the two challenges Obama identified in that speech back in 2013: the decarbonization of the U.S. electric system, which will play a critical role in fighting climate change, and the impacts of climate change that our electric system is already contending with — risks that appear poised to increase over the coming decades.

Understanding what the past decade of extreme weather can teach us about resilient decarbonization requires first understanding the nature of the risks climate change presents to the U.S. electric system, and the impacts it could have on the infrastructure that we will need to build in order to decarbonize.

[29] Obama, "Remarks by the President on Climate Change."

The Fourth National Climate Assessment (NCA), a quadrennial federal review of the science of climate change and its impacts on the U.S., issued this grim warning in 2018 about the state of U.S. public infrastructure as a whole:

> Our Nation's aging and deteriorating infrastructure is further stressed by increases in heavy precipitation events, coastal flooding, heat, wildfires, and other extreme events, as well as changes to average precipitation and temperature. Without adaptation, climate change will continue to degrade infrastructure performance over the rest of the century, with the potential for cascading impacts that threaten our economy, national security, essential services, and health and well-being.[30]

The Assessment specifically highlighted the ongoing and accelerating threats that climate impacts pose to our electric system, noting that:

> The Nation's energy system is already affected by extreme weather events, and due to climate change, it is projected to be increasingly threatened by more frequent and longer-lasting power outages affecting critical energy infrastructure…[31]

In this section, we will identify the types of risks that climate change poses to the U.S. electric system, before exploring some of the impacts it could have on the expanded, decarbonized system we previously discussed.

Having examined the broad spectrum of risks and impacts the electric system faces, we will then consider the value of focusing on the most extreme in our exploration of resilient decarbonization — particularly hurricanes and wildfires, which together have accounted for a plurality of the damages caused by extreme weather and climate disasters in the U.S. over the past decade.[32]

This will be underscored in Chapter 3, as we consider the impact that climate-driven extreme events have already had on the electric system, over the past decade — as well as research suggesting the role that climatic drivers played in their strength and intensity.

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[30] U.S. Global Change Research Program et al., "Impacts, Risks, and Adaptation in the United States," 30.

[31] U.S. Global Change Research Program et al., 175.

[32] NOAA Billions stat here

While decarbonization can greatly reduce climate risks to the electric system, we will still have to contend with our long (and ongoing) history of $CO_2$ emissions.

The gigatons of carbon dioxide we have already emitted, and continue to emit, will remain in the atmosphere — trapping heat — for long periods of time. As a result, the slow pace of the carbon cycle virtually ensure that we will face some degree of "locked-in" impact in the years to come.[33] As a result, it is only prudent that any effort to decarbonize the U.S. electric system first examine the climate risks and impacts it will have to contend with.

In an extensive report released in January 2020, the McKinsey Global Institute, working in partnership with the Woods Hole Research Center, highlighted seven key characteristics of physical climate risks.

First, climate risks are increasing in scope and scale, driven by the impacts of historical emissions coming to bear, with continued emissions leading to increased impacts in the future. While decarbonization can prevent the addition of additional risks, the inertia of the carbon cycle means that some risks that we have yet to realize cannot be avoided.

Second, climate risks are spatially defined and variable — both the magnitude of the risks and the impact they will have varies across regions, and depends on local characteristics. As a result, the cases we will soon examine span a wide geographic range.

Third, climate risks are non-stationary. These risks are characterized by constant, often rapid change. As a result, they point towards "not a new normal, but… a world of constant change." In each case, we will examine the ways in which regions have attempted to adapt to this constant change, in the way of climate-driven devastation.

Fourth, climate risks are nonlinear. As we will see repeatedly, tipping points and critical thresholds play a key role in determining the impacts of climate risks. Moreover, the convergence of multiple climate risks — whether all at once, or in succession — can exacerbate the impacts they have.

Fifth, climate risks are systemic. Given the vital role that the electric system plays as the backbone of modern society, this comes as no surprise. However, as we will see, even risks that only appear to threaten parts of the electric system can have impacts that threaten the

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[33] A strategy to achieve net negative global emissions could hypothetically mitigate even "locked-in" climate impacts to a degree, but we will focus here on net-zero decarbonization — a daunting enough task in its own right.

whole — including ones that extend far beyond physical damage, into the social and economic spheres.

Sixth, climate risks are regressive. As we will discover, the impacts of climate risk can vary starkly based on underlying socioeconomic factors — with regions and people who are already facing significant challenges (financial or otherwise), finding it most difficult to deal with climate impacts, and recover from their aftermath.

And finally, the report contends that when all these considerations into account, the United States is insufficiently prepared to deal with the risks at hand — a conclusion with which we will come to concur.

### 2.2.1 Types of climate risks and impacts

While climate change threatens nearly every sector of American society, from agriculture to public health, our focus here is on understanding the range of risks it poses to our electric system.

The National Climate Assessment offers a sampling of projected physical climate risks and their impacts on electric infrastructure,[34] including:

- *Higher average air temperatures*, as well as higher maximum temperatures during heatwaves, which could affect the performance of generators and power lines, as well as increase electric demand.
- *Higher water temperatures*, which could affect the performance of generators that rely on water for cooling (most modern coal, natural gas, and nuclear plants).
- *Shifts in snowpack melt timing and scale,* which could reduce hydroelectric generation.
- *Increased frequency and intensity of heavy precipitation events*, which could increase inland flood risks to electric infrastructure.
- *Increasing sea level rise,* which could increase flood risks to coastal and riparian electric infrastructure — particularly from storm surges.

[34] U.S. Global Change Research Program et al., "Impacts, Risks, and Adaptation in the United States," 191.

- *Increasingly frequent, intense, and lengthy droughts*, which could increase wildfire risk, affect the cooling of generators, reduce hydroelectric generation, and reduce the growth of biomass feedstock.
- *Increased frequency of convective storms involving thunderstorms, tornados*, *and high winds*, which could damage electric infrastructure.
- *Atlantic hurricanes with greater wind intensity and heavier precipitation*, that could threaten coastal electric infrastructure.

The risks fall into two broad categories: gradual change and extreme events. And the impacts on the electric system also fall into two categories: impacts on performance, and damage to infrastructure.

On the risks side, we see projections of both more extreme averages, and more extremes on average. Gradual increases in factors like air temperature and sea level cause persistent degradation — slowly reducing the performance of power lines through increased losses or causing daily, tidal flooding to creep further and further into the elevation safety margins of coastal substations. At the same time, extreme events like droughts, Atlantic hurricanes, and other severe storms will deal discrete blows to electric infrastructure — pushing electric systems to their limits by subjecting them to increasingly intense, increasingly frequent bursts of damage and disruption.

On the impacts side, we see a class of impacts that largely consist of changing climate conditions degrading the performance of electric infrastructure — whether by decreasing power line efficiency, straining transmission and distribution capacity, or making cooling of thermal power plants more difficult. The second primary class of physical impacts we examine are the destructive ones — wind taking down power lines and distribution poles or contributing to sudden wildfires, or storm surges flooding infrastructure and destroying sensitive electronics.

Generally speaking, gradual risks tend to degrade performance, while extreme events damage infrastructure. However, these are not fixed rules. A drought might gradually degrade the performance of water-cooled power plants, while also making environmental conditions ripe for a destructive power line-sparked wildfire.

Moreover, while these are useful categorizations, it's important to note that they are not firm boundaries. Though sea level rise and sea surface temperature increases are gradual risks, they might help strengthen an Atlantic hurricane's winds and boost the height of its storm surge.

Though we've surveyed a range of physical climate risks and impacts on the electric system, the risks at hand are far more than just physical. In the cases to come, we will argue that, based on historical experiences with extreme weather over the past decade, the non-physical risks of climate change might actually prove to have the more devastating impact on the electric system — especially when it comes to decarbonization effects.

### 2.2.2 Climate impacts on a decarbonized U.S. electric system

Having considered the range of risks and impacts that the U.S. electric system can expect to face over the coming decades, what can we say about how they might affect an expanded, decarbonized power system?

As we've previously noted, climate risks and impacts are hugely location-dependent: the Mid-Atlantic, the West Coast, and the U.S. Caribbean all face different climate risks, while the impact that those risks will have on each region depend on its own unique vulnerabilities. Per our discussion of NREL's work on the Interconnections Seams Study, we have concluded that electric system decarbonization will be a national affair, so an understanding of systemic climate risks and impacts will have to consider these regional variations.

We can begin by examining the existing vulnerabilities of communities across the United States to climate and extreme-weather events, with an eye towards understanding which regions might have the most existing vulnerability.

The EPA's Climate Resilience Screening Index (CRSI) project offers one potential answer. As part of a broader effort to examine the robustness of U.S. counties against climate impacts, the EPA calculated a normalized risk index (better thought of as a vulnerability index) for 3,135 county-level divisions.[35,36]

The vulnerability index has two major components: risk of exposure, and risk of losses. The exposure risk category aggregates the historical likelihood that a given county will be exposed to one of eleven types of environmental risk: hurricanes, tornados, inland and coastal

[35] Summers et al., "Development of a Climate Resilience Screening Index (CRSI): An Assessment of Resilience to Acute Meteorological Events and Selected Natural Hazards."
[36] Eight boroughs (county-level divisions) in Alaska were not included, due to a lack of data.

flooding, earthquakes, wildfires, drought, high winds, hail, landslides, and temperature extremes. It also accounts for the presence of hazardous sites in the county that could pose additional risks, such as Superfund sites. The loss risk category uses data from Arizona State University's SHELDUS natural hazards database,[37] in order to incorporate historical losses of life and property resulting from the eleven types of environmental risk in each county.

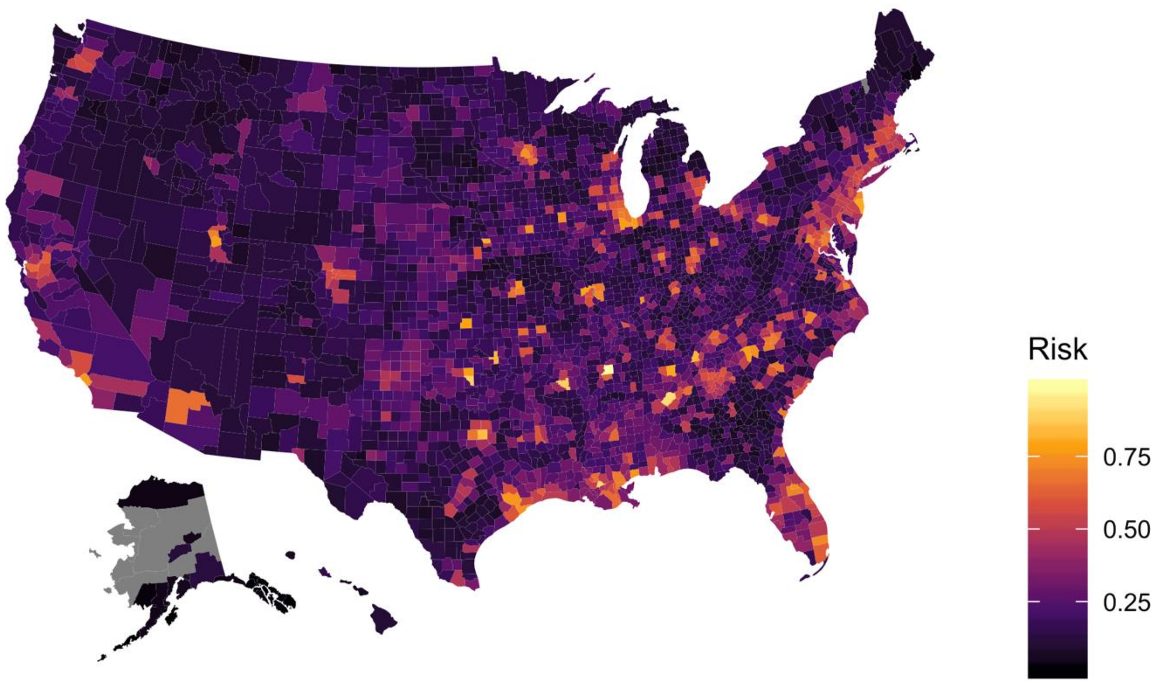


Figure 2. Relative vulnerability to climate and extreme weather events, indexed[38]

It's important to reiterate that the CRSI vulnerability index is based entirely on historical data — it does not reflect expectations about future growth/development or future climate shifts, but rather offers a high-level glimpse at how counties across the U.S. have historically fared against many of the same environmental risks that the NCA expects climate change to enhance over the coming decades, relative to one another.

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[37] Center for Emergency Management and Homeland Security, "Spatial Hazard Events and Losses Database for the United States (SHELDUS)."

[38] Summers et al., "Development of a Climate Resilience Screening Index (CRSI): An Assessment of Resilience to Acute Meteorological Events and Selected Natural Hazards."

We scraped the CRSI data from the EPA's final report, released in 2017, to produce Figure 2 — a nationwide map of the vulnerability index, with 1 being the highest relative risk, and 0 being the lowest relative risk.

A simple analysis of the CRSI vulnerability data reveals a number of notable clusters of vulnerability. In the Northeast, New Jersey has the highest vulnerability scores, particularly in the New York/NJ metro area and along the Jersey Shore. The DC-Maryland-Virginia metro also has elevated vulnerability scores, as do Coastal Connecticut and eastern Massachusetts.

Moving westward, we see hotspots surrounding the Detroit and Chicago metro areas, as well as elevated vulnerability regions in southern Indiana, Ohio, and western Pennsylvania.

Jumping south, we find that a band of elevated vulnerability runs diagonally across the Southeast, stretching from the Carolinas through Alabama. The Florida peninsula is another area of significantly elevated vulnerability, increasing as you go down the Eastern Seaboard towards Miami. And the Gulf Coast from Alabama through Texas has among the highest vulnerability scores in the country.

Continuing west, we see clusters of elevated vulnerability towards the Great Plains and across the Mountain West, with notable patches along the Mississippi River, and around Salt Lake City and southwestern Arizona. And finally, we see elevated vulnerability areas in California, just outside the San Francisco Bay Area, and just outside the Los Angeles metro area.[39]

How does this regional distribution of vulnerability to environmental risk compare to the expanded, decarbonized electric system we envisioned in Chapter 2.1? Looking back to Figure 1, we see that the major population/load centers — New York, Los Angeles, Chicago, Houston, the Bay Area, Miami — identified by NREL largely match up with the major clusters of environmental vulnerability. This makes intuitive sense, as the CRSI vulnerability index includes historical loss of life and property as part of its calculations — metrics which are generally higher in more populated, more developed metropolitan areas.

Looking closer, we see that the southern Sun Belt — the region NREL identifies as possessing high-quality solar resources — has consistently higher vulnerability levels, save

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[39] While Hawaii and Alaska are included for completeness, the EPA notes that the data in those states does not support firm assessments of vulnerability.

for a patch running through northern Texas and New Mexico. Similarly, we note that the Mississippi River/Great Plains bands of higher vulnerability fall right in the middle of the north-south area of high-quality wind resource identified by NREL.

While these analyses are fairly straightforward, they nevertheless leave us with an important conclusion about the impact of climate risks on the U.S. electric system. We observe that while relative historical vulnerability to the kinds of climate risks and impacts identified by the NCA varies significantly across the continental United States, it nevertheless overlaps substantially with the wind and solar resource corridors that will likely help drive a decarbonized electric system, as well as the major population centers that must be served.

Thus, we find that the areas of the U.S. that will play a critical role in decarbonizing the electric system have historically been among the most vulnerable to the kinds of environmental risks that we know climate change will exacerbate — vulnerability that will likely increase once the impacts of climate change are taken into account at the regional level.

These observations drew our attention to the New York/New Jersey and Northern California regions as areas of potential interest for case studies. While Puerto Rico was not included in EPA's CRSI data, it emerged as our third case study. Each of these regions is a major population center with historical vulnerability to environmental risks. In addition, each has experienced one (or more) major extreme weather events over the past decade — a common factor that is of particular interest to us, as we will now discuss.

### 2.2.3 A focus on extreme events

In examining the types of climate risks confronting the U.S. electric system, we identified two broad categories of risks: gradual change, and extreme events. In this thesis, we will focus primarily on cases involving extreme events — two major Atlantic hurricanes, and a series of devastating wildfires.

The opening editorial comment of a recent volume of *Nature Energy* noted that "climate change is a long-term phenomenon and so for a long time has been studied as such."[40] That's a hard statement to argue with — the textbook definition of "climate" is the average

[40] "Extremes Makeover."

of weather patterns, variables, and parameters over many years of observation.[41] So, why focus on climate extremes?

We argue that when it comes to the impacts of climate change on the electric system, and on the people it serves, it is not the gradual shifts but the extreme events that will have the greatest effect — not merely causing bursts of disruption and devastation, but also shaping long-term trends.

As we will explore, climate-driven extreme weather events can dramatically alter the infrastructural and organizational structure of electric systems and determine their long-term viability (both physical and fiscal).

More directly, we see that extreme weather events have long been the biggest threat to the U.S electric system — and their share of responsibility only seems to be growing.

| **Time Period** | **Billion-dollar disasters (annual average)** | **Associated Costs (annual average)** | **Associated Fatalities (annual average)** |
|---|---|---|---|
| 1980s (1980-89) | 28 (2.8) | $127.7B ($12.8B) | 2,808 (281) |
| 1990s (1990-99) | 52 (5.2) | $269.6B ($27.0B) | 2,173 (217) |
| 2000s (2000-09) | 59 (5.9) | $510.3B ($51.0B) | 3,051 (305) |
| 2010s (2010-19) | 119 (11.9) | $802.0B ($80.2B) | 5,212 (521) |
| Last 5 years (2015-19) | 69 (13.8) | $531.7B ($106.3B) | 3,862 (772) |
| Last 3 years (2017-19) | 44 (14.7) | $456.7B ($152.2B) | 3,569 (1,190) |
| **Overall (1980-2019)** | **258 (6.5)** | **$1.754.6B ($43.9B)** | **13,249 (331)** |

Table 1. Billion-dollar disasters, 1980-2019[42]

According to NOAA's National Centers for Environmental Information, from 1980 to 2019, weather and climate events caused an estimated $2.05 trillion in damage in the United States.[43] Of that, nearly 85% of the damage — $1.75 trillion — was caused by extreme weather events costing at least $1 billion each. This relationship applies when it comes to

[41] Grotzinger et al., *Understanding Earth*, 15.
[42] Smith and National Centers for Environmental Information, "2010-2019: A Landmark Decade of U.S. Billion-Dollar Weather and Climate Disasters."
[43] Smith and National Centers for Environmental Information.

electric systems, as well. The NCA found that "the principal contributor to power outages, and their associated costs, in the United States is extreme weather."[44]

Not only do extreme weather events make up most of the weather-related damage in the U.S., they've been steadily increasing their share over the past four decades. In line with the climatic trends we discussed in Chapter 2.2.1, NOAA notes that the fraction of total weather-resultant damage attributable to extreme weather rises as more recent years are added to the record: going from 75% when considering the 1980-2000 range, to 80% when that range is extended to 2010, and 85% when going all the way out to 2019.

As we see in Table 1, drawn from the NOAA analysis, sharply increasing trends can also be seen in the number of extreme weather events per decade, and in the number fatalities that have resulted. The past decade, in particular, has seen significant acceleration — just the three years from 2017-2019 saw more damage from extreme weather events than the entire two decades from 1980 to 1999, and more fatalities than any individual preceding decade.

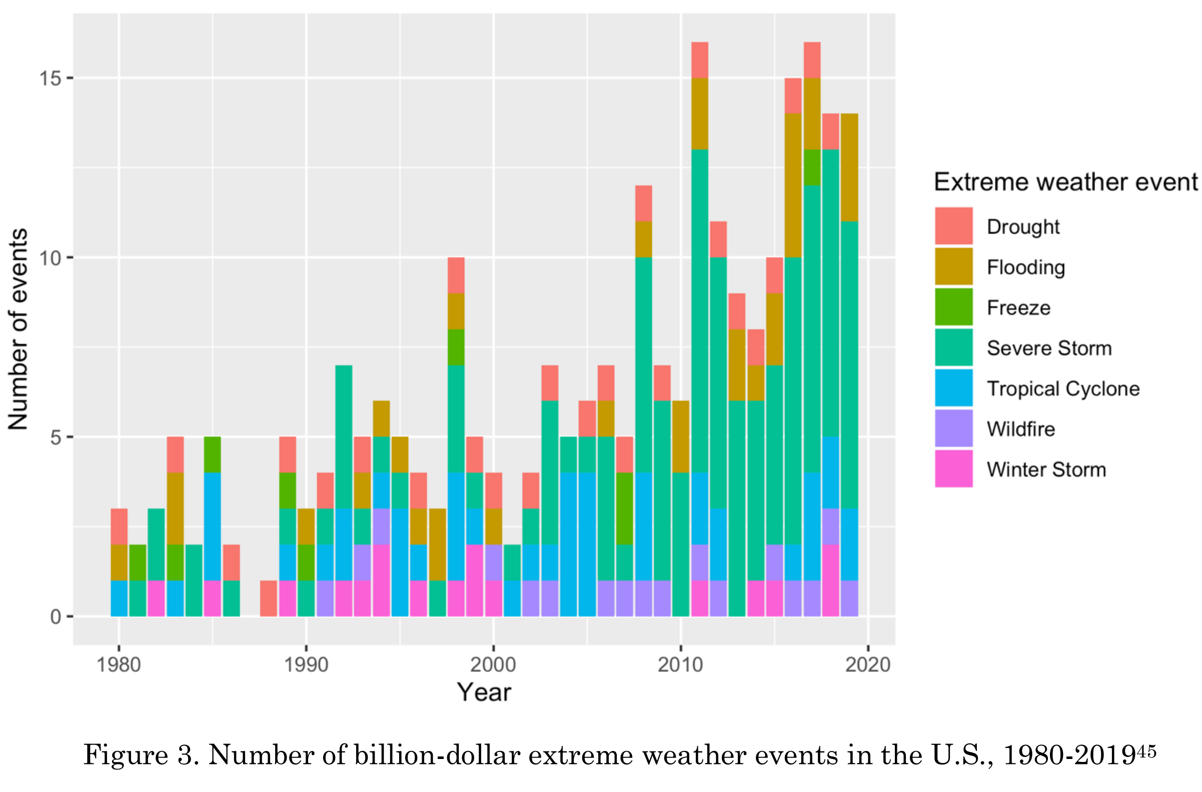


Figure 3. Number of billion-dollar extreme weather events in the U.S., 1980-2019[45]

[44] U.S. Global Change Research Program et al., "Impacts, Risks, and Adaptation in the United States," 188.

[45] National Centers for Environmental Information, "U.S. Billion-Dollar Weather & Climate Disasters: 1980-2020."

What's been driving this surge in damage from billion-dollar disasters? From looking at the number of extreme weather events by type in Figure 3, based on the data underlying the NOAA analysis, one might be led to believe that the increase in severity is a result of the dramatic surge in the number of severe storms occurring, perhaps in concert with increased number of flooding events.

However, a look at Figure 4 reveals the surprising truth: Atlantic hurricanes have been responsible for the overwhelming majority of damage over the last four decades.

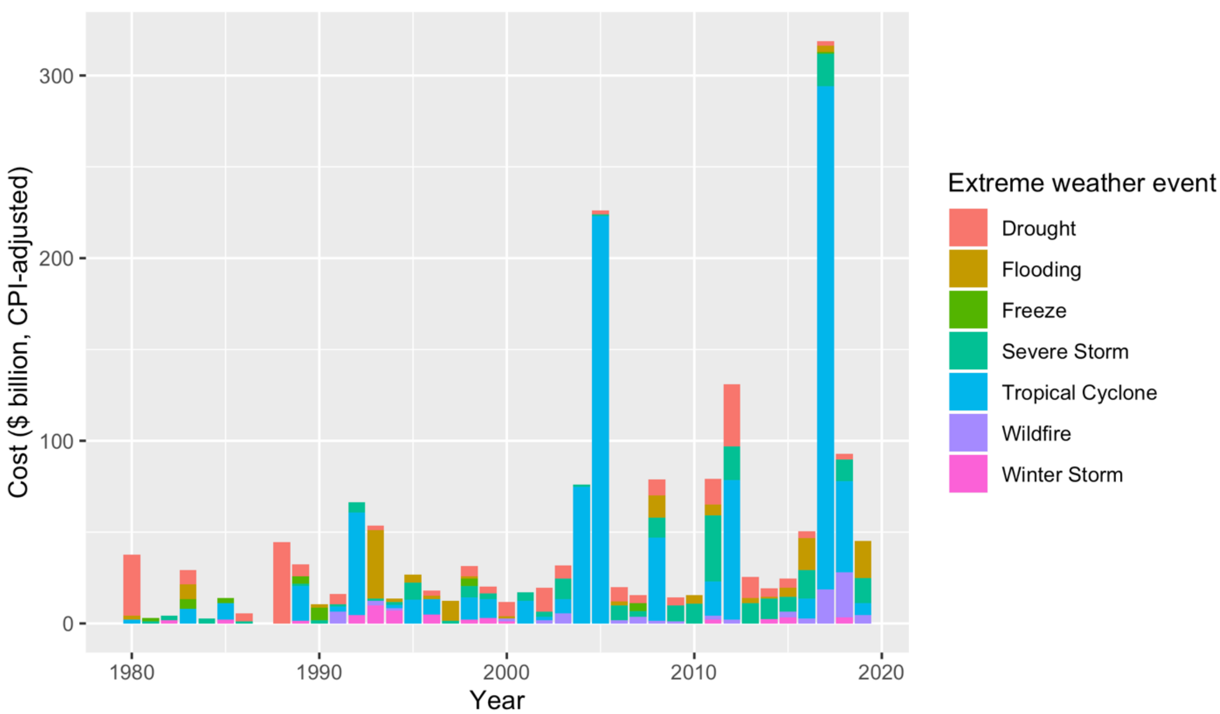


Figure 4. Costs of billion-dollar extreme weather events in the U.S., 1980-2019[46]

Looking closely at the data underlying Figure 4, we can identify the events driving the three visible spikes in costs. The 2004 spike resulted from a highly active Atlantic hurricane season, while the majority of the costs in 2005 were the result of a single storm: Hurricane Katrina. The 2012 spike is largely attributable to Hurricanes Sandy and Irene, in addition to a nationwide drought that rivaled that of the 1930s. And the 2017 spike

[46] National Centers for Environmental Information.

stems from that year's record-shattering Atlantic hurricane season, in which Hurricanes Harvey, Irma, and Maria pummeled the Gulf Coast, East Coast, and Puerto Rico, respectively.

In addition to the increasingly shocking devastation that hurricanes have caused over the past decade, it's worth noting the massive increase in wildfire damage that's occurred just in the last three years. Extreme wildfire seasons caused $43.2 billion dollars in damages during 2017 and 2018 alone — more than in the thirty-seven preceding years, combined.

Given these remarkable statistics, it seems quite reasonable for us to focus our attentions on the risks posed to the U.S. electric system by hurricanes and wildfires — the overwhelmingly largest driver of extreme weather damage, and one that has seen explosive growth over the past three years, respectively.

For completeness's sake, we must consider the limitations of this analysis. For one, NOAA's focus on "billion dollar" events could be causing some degree of thresholding — leaving out events that fall just short of the billion dollar mark.[47] While this concern appears to be assuaged by NOAA's statistics on the fraction of total weather damages that stem from extreme weather events (85%), it is nevertheless possible that smaller events are systematically undercounted. After all, a major hurricane or wildfire nearly always merits a substantial emergency response that involves a thorough accounting of the damage sustained. On the other hand, the costs of smaller, but more frequent events like severe rainstorms or winter storms are much more likely to be overlooked — even though they may be significant in the aggregate. Additionally, the impacts of some of the most notable gradual climate risks — such as sea level rise and temperature increases — are just now starting to be felt, and their costs are still a matter of great uncertainty.

Nevertheless, the importance of extreme weather impacts on the electric system is quite apparent, both when looking at the historical data and when considering projected future trends.

The four extreme weather events we examine in depth in this thesis — Hurricane Sandy, Hurricane Maria, and the 2017 & 2018 California wildfire seasons — cost nearly $200 billion. Out of the 119 billion-dollar extreme weather events that struck the U.S. over the past decade, just these four make up one quarter of the cost.

[47] It's worth noting that the cost data we use here are CPI-adjusted for inflation, which brings several historical events that otherwise wouldn't be counted above the billion-dollar threshold.

### 2.2.4 Key takeaways on climate risk and impacts

Our exploration of the climate risks and impacts facing the U.S. electric system has left us with a rather stark picture.

We've examined the range of gradual change and extreme weather risks that climate change will likely exacerbate in the United States, and considered how they might impact a decarbonized, expanded power system.

By comparing metrics of historical vulnerability to environmental risk with the geographies that will likely be major sites of electric system expansion and investment, we find that the most vital regions are also the ones that have historically faced the greatest risk — an intuitive result of having a massive, nationwide electric system. This means that any effort to decarbonize our electric system will require building gigawatts of new infrastructure in regions that we know are currently facing and will continue to face the impacts of climate change.

And we got a look at which impacts matter most, recognizing that extreme weather events cause the overwhelming majority of weather and climate-related damages in the U.S., and that they have accelerated in intensity at an alarming rate over the past decade, and indeed, over just the past three years.

Taken together, we see that any effort to decarbonize the U.S. electric system will, by geographic necessity and climatic reality, take place in harm's way — in the sights of an ongoing surge in extreme weather unlike any we have seen in the past forty years. As a result, we now turn to the animating question of this thesis: how can we build a decarbonized power system in the face of climate risks?

The answer, as we will now argue, is by putting the principles of resilience at the core of our decarbonization efforts.

## 2.3 Resilience & resilient decarbonization

The aim of decarbonization efforts is to limit the severity of climate risks and impacts, by eliminating $CO_2$ emissions — protecting electric systems by reducing the threats they face. Resilience efforts, on the other hand, start from the opposite assumption. They assume that climate risks *are* present, that climate impacts *will* occur — and then ask how to ensure that electric systems can maintain maximum functionality in the face of these threats.

Resilience is, at its core, an acknowledgement that in a complex, interconnected system like the U.S. electric system, failures will inevitably occur. This is especially true when confronting risks like those from climate change and the resulting extreme events, which Chester, et al. (2020) argue "are entirely characterized through uncertainty."[48]

The National Academies of Science defines resilience as "the ability to prepare and plan for, absorb, recover from, or more successfully adapt to actual or potential adverse events."[49] Where decarbonization would reduce climate risks to electric systems, resilience-based efforts instead seek to prepare electric systems to deal with whatever climate risks might materialize.

Often characterized as designing for "graceful failure," resilience-based approaches focus on ensuring that electric systems are able to absorb a hit from what would otherwise be a devastating extreme weather event, while minimizing the resulting damage and disruption, and then return to their normal conditions as quickly and effectively as possible.

Thus far, we've established that decarbonizing the U.S. electric system will require a massive, nationwide infrastructure that will span many of the regions that are most vulnerable to extreme weather events — events that we cannot yet adequately predict. We've also recognized that extreme weather events — which have the potential to overwhelm existing systems — are increasingly responsible for the lion's share of weather and climate damages in the U.S. As a result, we are faced with the challenge of building a decarbonized electric system that we know will be in harm's way from day one, and protecting it from the extreme weather risks that we know it will have to face.

Putting resilience at the core of our electric system decarbonization efforts would address the key challenges raised by the risks of climate-enhanced extreme weather. A focus

[48] Chester, Underwood, and Samaras, "Keeping Infrastructure Reliable under Climate Uncertainty."
[49] National Research Council, *Disaster Resilience*, chap. 3, p.16.

on resilient decarbonization would insulate electric systems against the inherent uncertainties of climate risks, while structuring them to fail gracefully in the face of extreme weather events, in order to recover quickly and effectively with minimum damage and disruption. This offers a compelling alternative to what we will see again and again in our case studies: systems that are able to stand firm up to a certain threshold or tipping point, before catastrophically failing in a manner that makes recovery quite challenging.

While this risk and protection-centric argument for incorporating resilience into electric system transformations is quite compelling, we argue that it leaves out one of resilience's key benefits — its ability to enhance and enable decarbonization efforts.

Decarbonization and resilience are not two separate threads, but rather two sides of the same coin. Thus far, we have talked about how we can maximize decarbonization, while also minimizing risk to electric systems. However, the animating principle of this thesis is that decarbonization and resilience are just two sides of the same coin. A decarbonized electric system is, in general, more resilient in the face of climate risks and impacts. And an electric system designed with climate resilience in mind can actually serve as a positive force for decarbonization.

Putting resilience at the core of our efforts to decarbonize the U.S. electric system will not only enable it to better handle the risks of climate-driven extreme weather, but also enhance and enable decarbonization itself.

### 2.3.1 Climate resilience in electric systems

Resilience is far from a novel concept in the world of electric systems, but it's generally discussed through the lens of reliability.

Since 2005, the North American Electric Reliability Corporation (NERC) has enforced standards for electric system reliability across the bulk power (transmission) system, with the aim of "assur[ing] the effective and efficient reduction of risks to the reliability and security of the grid."[50] NERC defines reliability in terms of two key concepts:

> *Adequacy*: The ability of the electricity system to supply the aggregate electrical demand and energy requirements of the end-use customers at all times, taking into account scheduled and reasonably expected unscheduled outages of system elements.
>
> *Operating Reliability*: The ability of the Bulk-Power System to withstand sudden disturbances, such as electric short circuits or the unanticipated loss of system elements from credible contingencies, while avoiding uncontrolled cascading blackouts or damage to equipment.[51]

Simply put, adequacy is the electric system's ability to match the supply of generation with the demand for electricity. Operating reliability encompasses a subset of what we'd consider resilience, with its focus on withstanding disturbances while minimizing systemic disruption and damage.

However, operating reliability is focused on standing firm against the risks posed by "credible contingencies." This approach tends to lead to efforts to design electric systems to be able to continue operation up to a certain level of stress, determined probabilistically based on historical information.

Chester, et al. (2020) highlight the limits of such an approach in the face of uncertain climate risks. They argue that given the long planning and deployment timescale of large infrastructure projects like electric systems, they were likely not designed to meet the climatic conditions they are currently facing — particularly in light of the increase in extreme

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[50] NERC is a private, non-profit corporation that was granted regulatory enforcement powers by FERC under the Energy Policy Act of 2005, following the 2003 Northeast blackout.

[51] North American Electric Reliability Corporation, "Reliability Terminology."

weather that we've previously noted. This is further exacerbated by the fact that most existing infrastructure wasn't designed with projections of future climate variations in mind. The NCA notes that over half of U.S. energy infrastructure is more than twenty years old, including over 70% of transmission lines and transformers, while the average age of a power plant is over 30 years old.[52] While this is relatively young for massive pieces of infrastructure that are designed to last decades, the average age of electric system components still means that they were likely not designed to meet the demands and stressed of present or future climate risks.

But as a number of scholars have emphatically noted, even when planners do take into account projections of future climate risks and impacts, those projections still contain a great deal of uncertainty.[53,54,55] Modern climate models — both the general circulation models (GCMs) used for simulating climate dynamics, and the integrated assessment models used to estimate damages from climate risks and impacts — still end up with sizable bands of uncertainty when attempting to forecast the impacts of climate-driven extreme weather at a localized level, which makes using them for hyperlocal electric infrastructure siting and system design purposes challenging. This is not an indictment of the models themselves, but rather a recognition of the continued difficulty of making computationally-intensive climate projections under significant uncertainty, and then translating those projections into impact estimates with high spatial resolution.

In light of this uncertainty, one option might be to "harden" the electric system — design and build it to meet even the most extreme of weather conditions. While hardening efforts — such as burying power lines and elevating substations — are an integral component of resilience efforts, "harden everything" turns out to be a prohibitively expensive measure.

A 2019 analysis by Bloomberg New Energy Finance found that burying PG&E's 18,000 miles of transmission lines alone could cost more than $67 billion. The Bloomberg analysis noted that a 230 kV high-voltage overhead transmission line that normally cost $320,000 per mile could cost as much as $2.6 million per mile to install underground — with other voltage classes costing as much as 36 times more to install underground than their

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[52] U.S. Global Change Research Program et al., "Impacts, Risks, and Adaptation in the United States," 194.
[53] Otto et al., "Event-Based Models to Understand the Scale of the Impact of Extremes."
[54] Chester, Underwood, and Samaras, "Keeping Infrastructure Reliable under Climate Uncertainty."
[55] McCollum et al., "Energy Modellers Should Explore Extremes More Systematically in Scenarios."

overhead counterparts.[56] ConEd cited a similar estimate of $60 billion as the potential cost of burying just its distribution system.[57]

Moreover, a “harden everything” approach would likely lead to a misallocation of limited infrastructure investments. Chester, et al. (2020) observe that while the majority of climate impacts involve intensification of risks, that intensification isn’t geographically uniform — existing vulnerability to climate risk varies by location, as do risk trends. While precipitation might increase significantly in a certain region, it may already be well-suited to handle the change. Similarly, an increase in precipitation in one region might be coupled with a decrease in another. The CRSI data we examined supports the idea that there is a significant amount of geographic variation in vulnerability to climate risks. A “harden everything” approach would make it harder to focus resources on those regions that are most vulnerable to climate risks.

As the NCA suggests, a resilience-based decarbonization approach should seek to strike a balance between the electric system’s current, largely reactive posture when it comes to extreme weather, and an overly-proactive “harden everything” approach — incorporating both proactive, whole-of-system efforts to anticipate climate risks and preemptively harden infrastructure to reduce climate impacts, while laying the groundwork needed to respond and recover effectively when those impacts inevitably occur.[58]

In the case studies to come, we will see that the value of resilience lies not in preventing climate impacts from affecting the electric system at all, but in ensuring that those impacts are as minimal as possible, and don’t push it past tipping or breaking points — leading to catastrophic system failures, as occurred during Sandy, Maria, and the California wildfires. Put more colloquially, resilience focuses less on how hard of a hit an electric system can absorb without failing, but how disruptive that failure is and how quickly it can recover in its aftermath.

Resilience is also particularly well-suited when attempting to design infrastructure in the face of an uncertain range of extreme weather risks. As Chester, et al. (2020) note “failure most often occurs when design conditions are exceeded, not simply because the asset has increased exposure.” A resilience-based approach would put concerns about exceeding design

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[56] Baker, “PG&E Could Put Power Lines Underground, But It’s Very Expensive.”
[57] Gallucci, “Rebuilding Puerto Rico’s Power Grid.”
[58] U.S. Global Change Research Program et al., “Impacts, Risks, and Adaptation in the United States,” 185.

conditions front and center. McCollum, et al. (2020) offer a novel categorization of extreme risks that builds on the simple "gradual change vs. extreme event" dichotomy we have relied on thus far. They identify three categories of extreme risks: transient events, disruptive drivers, and unexpected outcomes, depicted graphically in Figure 5.

Transient extreme events are temporary events that are "anticipated but not necessarily well planned for," such as an extreme storm that tests record windspeeds. These are events that exceed our expectations of probable weather patterns, but are still within a range that we'd consider reasonably possible.

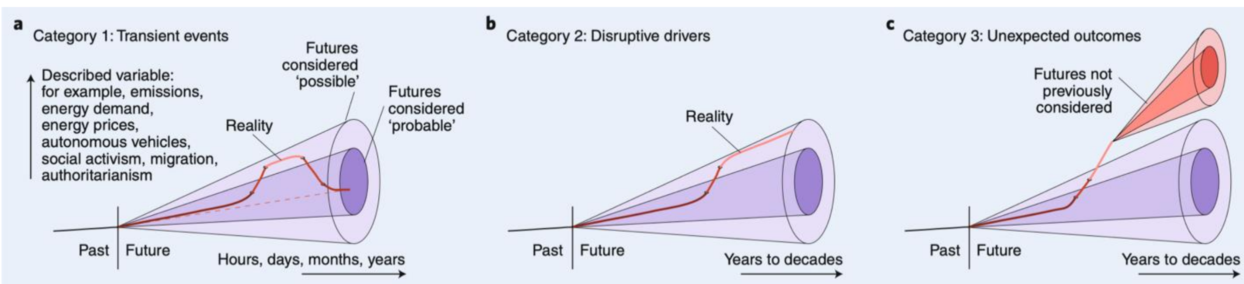


Figure 5. Classification of extreme events from McCollum, et al. (2020)

Under our current categorization, we'd consider disruptive drivers to be a second-order effect of gradual change: the authors define them as trends that enable events "beyond common perceptions of a probable future." These aren't extreme risks themselves, but rather gradual risks like sea-level rise which unexpectedly push what would normally be a transient extreme event out beyond probable expectations of weather patterns, to the edges of what we'd consider possible.

And finally, unexpected outcomes: extreme events which fall outside the range of what we'd consider possible. McCollum, et al. describe these events as "diverging so fundamentally from the status quo, they could push society to states where it has never been, or ever imagined being." The authors liken these to "black swan" events, the metaphor coined by popular statistician Nassim Nicholas Taleb in his 2007 book of the same name, for unforeseen yet high-impact events.[59] They offer paradigmatic shifts like the concept of multi-decade war

[59] Taleb, *The Black Swan*.

on terror, or technological advances (such as the introduction of widespread electric systems) that "redefine what is feasible."

When judged against this taxonomy, resilience appears to be a winning strategy for power systems. The combination of system hardening and graceful failure/effective recovery planning that resilience-based approaches encompass make it more likely that an electric system would be able to endure a" transient extreme event" with reduced damage, and recovery quickly. The focus on pre-emptively planning for future risks, as opposed to simply recovering from extreme events after they strike, would encourage systemic shifts to deal with "disruptive drivers." And the emphasis on being able to fail gracefully, instead of break catastrophically, would serve electric systems well in the event of an "unexpected extreme event" that exceeds the far bounds of what the system was designed to handle.

While the extreme events we consider in our cases appear at first glance to be "unexpected outcome events" — two uncharacteristically devastating hurricanes, and a streak of wildfire activity without precedent — they are properly transient extreme events. This is because, as we have seen from our survey of the NCA, we have ample indications that Atlantic hurricanes are poised to strengthen, and that the climatic conditions that drive wildfires in the Western U.S. are intensifying. While it's true that limited predictive and modeling capacity when it comes to extreme events has proven to be a hindrance, these events certainly did not "diverge so fundamentally from the status quo, they could push society to states where it has never been, or ever imagined being."

Having considered the value that a resilience-centric approach would bring to electric systems, we are left with the distinct feeling that these are not groundbreaking ideas — and indeed they are not. As the NCA notes, "a significant portion of climate risk can be addressed by mainstreaming; that is, integrating climate adaptation into existing organizational and sectoral investments, policies, and practices, such as planning, budgeting, policy development, and operations and maintenance." A growing body of research suggests that one of the most significant value propositions of resilience for electric systems, beyond providing protection against extreme events, is the ability to shine a light on climate risks for which they are, per the McKinsey/Woods Hole report, insufficiently prepared. Work on the legal[60] and financial[61] systems suggests that both systematically underestimate the

[60] Gundlach, "Climate Risks Are Becoming Legal Liabilities for the Energy Sector."
[61] Griffin, "Energy Finance Must Account for Extreme Weather Risk."

liabilities that extreme weather events can create for electric systems. As we will confirm repeatedly through our case studies, these liabilities — in the form of crippling debt burdens and lawsuits — can prove just as devastating as the physical impacts of climate risks.

Taleb has recently expressed his frustration that the ongoing COVID-19 pandemic has been labeled a "black swan" event, arguing that there were plenty of warnings that a global pandemic could eventually occur, but our existing systems and infrastructure failed to heed them, and were thus unable to handle the sudden, extreme changes that COVID-19 forced upon them.[62] By the same token, we will argue that it was far from inconceivable that a hurricane might threaten Puerto Rico or the New York/New Jersey metro area, or that the combination of drier, windier climatic conditions and aging electric infrastructure could spark devastating wildfires in Northern California. But because of a lack of foresight and recovery capacity across electric systems, and the financial and legal systems that they are subject to, what should have been extreme, but transient events instead became unexpected catastrophes.

By placing resilience at the core of how we plan our electric systems, we can not only better protect them against climate risks and prepare them to recover from their impacts, but also help drive the systemic transformations needed to reduce those risks at the source.

### 2.3.2 Resilient decarbonization: is a crisis a terrible thing to waste?

While resilience is generally framed as a protective measure, we contend that it should also be viewed as a constructive one — an opportunity to drive positive, systemic change, like decarbonization.

The NCA supports this optimistic perspective, contending that "resilience actions can have co-benefits, such as developing and deploying new innovative energy technologies that increase resilience and reduce emissions."[63] In our case studies, we will dive deeper into this claim. In California, we will see how a lack of climate resilience is now threatening one of the nation's most decarbonization-driven electric systems. In New York and New Jersey, by

[62] Avishai, "The Pandemic Isn't a Black Swan but a Portent of a More Fragile Global System."
[63] U.S. Global Change Research Program et al., "Impacts, Risks, and Adaptation in the United States," 185.

contrast, we will see how efforts to build resilience have worked in tandem with a push to decarbonize electric systems.

Throughout all three cases, we will examine the resilience of various power systems to extreme weather events, and consider the ways in which resilience did (or didn't) become a priority for the affected institutions, in their aftermath.

However, we will also consider the ways in which efforts to increase the climate resilience of electric systems, and the extreme weather disasters that precipitate them, can serve as catalysts — encouraging and enabling decarbonization efforts.

The idea that our collective response to disasters can be an opportunity to push for transformative change is nothing new. On December 16, 2008, economist Christina Romer sat in the Chicago transition offices of a newly-elected Barack Obama, and told him, "Mr. President, this is your holy-shit moment." It is a moment that reporter Michael Grunwald describes as the "opening scene of [the Obama] presidency's creation myth."[64]

That creation myth, which Grunwald describes in his book *The New New Deal*, is the story of how the newly-elected administration inherited the economic chaos of the 2008 financial crisis and responded with the American Recovery and Reinvestment Act, an $831 billion package that was intended not merely to rescue the floundering U.S. economy, but to do so in part by laying the foundations for key long-term policy initiatives, by investing in clean energy technology and R&D, healthcare reform, an education overhaul, and economic relief for families in need.

In the meeting, Romer, who would go on to chair Obama's Council of Economic Advisers, was urging the president-elect that another round of fiscal stimulus on a massive scale would be needed to stabilize the economy — something on which there was a broad consensus within both Obama orbit and the broader U.S. economic and financial communities. However, what this stimulus should be directed towards — what it ought to be spend on — was the subject of great debate within the Obama campaign, transition, and administration, from the early days of the crisis in 2007 to the passage of ARRA in February 2009.

The two sides of that debate are best encapsulated by the evolution that Larry Summers, another Obama economic adviser who would go on to chair the National Economic Council, would experience over this time. In December 2007, Summers gave a speech at the

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[64] Grunwald, *The New New Deal*, 113.

Brookings Institution in Washington, where he argued that stimulus efforts to deal with the economic crisis then brewing should be *"timely, targeted, and temporary"* — they should yield immediate results, be focused on the drivers of the crisis, and not require long-term commitments.[65] However, over the next year, as a housing crisis turned into a broader financial crisis, Summers began to believe that much more ambitious, long-term actions would be necessary. Speaking at a conference just after the election, Summers introduced a new alliterative checklist of "speedy, substantial, and sustained," calling for a response that still got off the ground quickly, but one that addressed the broader, systemic challenges the economy faced, through long-term commitments.[66]

Now, what does a prominent economist's policy evolution have to do with resilient decarbonization of the power sector? While Summers was concerned with the challenge posed by a financial crisis, his two points of view apply equally well to any effort to use a crisis as a catalyst for long-term policy goals.

On one hand, there is a school of thought that will argue for directness: the response to a crisis should respond to that crisis — nothing less, nothing more. If a hurricane knocked out Puerto Rico's electric system, the response should restore that system as it was, and perhaps also make some changes to ensure that it can better withstand future hurricanes.

However, a second school of thought exists which advocates much broader, systemic responses: a crisis is an opportunity to tackle a larger, underlying problem. A hurricane knocked out Puerto Rico's electric system? Well, the best projections we have indicate that this sort of thing is more likely if carbon emissions continue at current levels — perhaps there's a way to protect electric systems from these storms that could also help reduce how bad they're going to get in the future.

In 2004, economist Paul Romer[67] (who would later win the Nobel Prize for his work on how public policy can drive technological change) memorably stated that "a crisis is a terrible thing to waste." The phrase would become commonplace during the financial crisis, with Obama's first chief of staff, Rahm Emanuel adding, "it's an opportunity to do things that you think you could not before."

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[65] Summers, "The State of the U.S. Economy: Risks of Recession, Prospects for Policy."
[66] Grunwald, *The New New Deal*, 99.
[67] No relation to Christina Romer

Can the recovery from an extreme event become a catalyst for transformative structural shifts in complex systems like the U.S. electric system? In their book *Building a Resilient Tomorrow*, Alice Hill and Leonardo Martinez-Diaz emphatically argue in favor of the idea, citing numerous instances in places ranging from Florida to Holland where devastating extreme weather events led to what they call "no more" moments — tipping points that led political, social, and business leaders to dramatically revise their approaches to, in this case, flood management.[68] However, those were relatively targeted measures — a flood management response to devastating floods.

The ongoing COVID-19 pandemic offers a counterpoint of sorts. Global stay-at-home orders have led to unprecedented economic disruption, necessitating more than $2.35 *trillion* in stimulus spending by the U.S. Congress.[69] The Democratic majority in the U.S. House of Representatives has repeatedly floated the idea that stimulus spending could be put toward decarbonization efforts and other electric infrastructure investments, following in the vein of Obama's ARRA energy investments. However, these proposals have sparked significant controversy and repeatedly fallen flat — suggesting a hesitance to use a recovery to take long-term, "waste no crisis" action.[70][71]

Crises aside, our national appetite — and capability — for large-scale, transformative infrastructure projects seems to have waned. Political theorist Francis Fukuyama argues that U.S. institutions have become crippled by "vetocracies" — participatory processes that overly diffuse power, leading to a bias against transformative or disruptive projects.[72] Whether crises really are "opportunit[ies] to do things that you think you could not before" remains to be seen.

In the case studies that follow, we will explore this issue in great detail, in an effort to assess the connection between resilience and decarbonization — and determine if resilience efforts in the wake of a crisis really can serve as positive forces for decarbonization.

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[68] Hill and Martinez-Diaz, *Building a Resilient Tomorrow: How to Prepare for the Coming Climate Disruption*.
[69] Van Dam, "The U.S. Has Thrown More than $6 Trillion at the Coronavirus Crisis. That Number Could Grow."
[70] Tollefson, "Climate vs Coronavirus."
[71] Brady, "Climate Change Push Fuels Split On Coronavirus Stimulus."
[72] Klein, "Why We Can't Build."

### 2.3.3 Key takeaways on resilient decarbonization

Over the course of this chapter, we've laid out the three foundational principles upon which this thesis rests.

First, we've shown the urgent need to decarbonize the U.S. electric system, and the massive scale of infrastructure buildout that such an effort would require.

Second, we've explored the climate risks and impacts that the U.S. faces, as well as the broad geographic distribution of vulnerability to those risks. As a result, we recognized that a decarbonized electric system will almost certainly have to be built in harm's way, and will inevitably have to contend with the climate-driven increase in extreme weather that has occurred over the past four decades, which shows no sign of letting up.

And finally, we've identified the principle of resilient decarbonization as a potential solution to this conundrum. We argue that by combining adequate levels of system hardening with a focus on proactive planning, graceful failures, and effective recoveries, we can not only ensure that our electric system is better equipped to handle the risks of climate-driven extreme weather, but also enhance and enable its decarbonization.

As we will soon see, these ideas have direct implications for the way we deal with extreme weather, resilience, and decarbonization of the electric system. They mean asking whether the disaster recovery money we're handing out should have some climate targets or decarbonization principles baked into it. They mean asking whether the person at an electric utility who's in charge of pushing for low-carbon generation should also be the same person who's in charge of pushing for reconfiguring distribution systems to automatically island themselves off to prevent cascading failures.

Barrels of ink and trillions of bytes have been expended over the past decade, exploring the methods for decarbonizing electric systems, and arguing that the time for massive investments in electric system resilience.

In this thesis, we seek to probe the intersection of those two conversations. How could we use the growing push to decarbonize our electric systems to also help those systems best prepare for and recover from the risks and impacts of climate change? How could efforts to rebuild or prepare power systems for those same risks and impacts actually help lay the groundwork for our efforts to decarbonize, or even serve as a vehicle for decarbonization itself?

By asking these questions, we hope to connect these debates — to make the case that resilience ought to be an integral component of decarbonization. As we look at the big plans Puerto Rico has for its (still-pending) disaster relief money, the challenges that a lack of resilience have thrust in front of PG&E's quest to lead the nation in clean energy, and New York & New Jersey's disaster-driven steps towards resilience, we want to examine how better preparing for disasters might help us build an electric system for the future.

To do this, we will now examine what three of the most devastating events from the past decade of extreme weather can teach us about the need for resilient decarbonization, the value it offers, and the conditions that can launch it forward or hold it back.

# 3 Lessons from a decade of extreme weather

The past decade saw extreme weather cause more damage in the United States than any other on record. From 2010 through 2019, 119 extreme weather events caused a total of more than $800 billion and claimed over 5,200 lives.[73]

Over the course of this chapter, we will dive into the stories of three of the most devastating extreme weather disasters of the past decade — each of which had a profound impact on the electric systems of the communities they struck.

We will examine the events of each extreme weather event, as well as the underlying drivers that turned it into a disaster for the affected communities and their electric systems. Based on this, we'll consider the efforts that were made in the aftermath of each disaster to build resilience against the particular threats faced by electric systems. And in two of our cases, we will see how those efforts fared in the face of key tests of the electric system's resilience.

First, we'll consider how Puerto Rico fared in the aftermath of Hurricane Maria, which struck the island in 2017. We'll examine how the growing risk from climate-driven Atlantic hurricanes, a legacy of financial challenges dating back centuries, a troubled utility, and a beleaguered response effort all came together to cause the world's second-largest blackout. We'll then consider the steps that Puerto Rico has taken to increase its electric system's resilience, and see how those efforts fared in the wake of a series of earthquakes that struck the island in early 2020.

Second, we'll examine the 2017-2019 wildfire seasons in Northern California, the most devastating on record. We'll piece together how a growing risk from climate-driven wildfires, the troubled history of the Pacific Gas and Electric Company (PG&E), and the struggles of California regulators and legislators all came together to send the nation's largest investor-owned-utility into bankruptcy, in the face of $30 billion in liabilities for sparking wildfires. We'll examine the impacts of PG&E's unprecedented bankruptcy, and examine the resilience efforts that both it and the state of California have undertaken in the wake of the 2017-2018 wildfires. Then, we'll see how those efforts fared in the face of the 2019 wildfire season, as PG&E employed a novel series of preemptive power shutoffs.

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[73] Smith and National Centers for Environmental Information, "2010-2019: A Landmark Decade of U.S. Billion-Dollar Weather and Climate Disasters."

And finally, we'll turn to Superstorm Sandy, which served as a wakeup call for the New York/New Jersey area when it made a sudden left turn towards the region in 2012. We'll consider the particular risks that climate-enhanced Atlantic hurricanes pose to the Northeast, before turning to the remarkable project of resilient decarbonization that has taken hold in New York and New Jersey over the past decade.

By examining these historical tragedies, we will seek to identify both bright spots and cautionary tales, and extract a series of cross-cutting lessons that can help inform and enable future efforts at resilient decarbonization of electric systems

## 3.1 Puerto Rico (2017-2020)

*A commonwealth with not a lot o' wealth, a not-quite nation,*
*seventy-billion-dollar topic of conversation…*

*This is an island a hundred miles across*
*A hurricane is coming and we're running' up a loss.*

– Lin Manuel Miranda, April 24, 2016[74]

In the aftermath of Hurricane Maria, Puerto Rico's electric system stands as a reminder not only of the critical importance of resilient decarbonization, but also of just how difficult that process can be — especially in regions that are already dealing with weakened institutions and societal challenges. In the aftermath of a disaster, a lack of resilience combined with a legacy of institutional constraints dramatically hindered recovery efforts — leading to the second-largest power outage in history.

Hurricane Maria was a disaster of tragically historic proportions. In Puerto Rico, the storm claimed just under three thousand lives[75] and caused an estimated $100 billion in damages.[76] And in its wake, Puerto Rico endured the largest electric power blackout in U.S. history, and the second largest ever in the world.[77] It would take 189 days to bring power back to 95% of Puerto Ricans and 328 days — nearly eleven months — before power was fully restored across the island.

In the two and a half years since Maria made landfall in Puerto Rico's southeastern coast, two questions have dominated the discussion — both scholarly and public — surrounding the storm and its aftermath.

First, *how did this happen?* What were the confluence of factors that left over three million American citizens without electricity for the better part of a year? Fingers have been pointed at the freak one-two punch of two back-to-back Category 4 hurricanes, Puerto Rico's colonial legal legacy, endemic corruption and weakened institutions, crippling debt and

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[74] Miranda and Lacamoire, *Puerto Rico (A Hundred Miles Across)*.
[75] Initially listed as 64 deaths, the official statistic was conservatively revised to 2,975 deaths, and remains a point of great controversy.
[76] National Centers for Environmental Information, "U.S. Billion-Dollar Weather & Climate Disasters: 1980-2020."
[77] Houser and Marsters, "The World's Second Largest Blackout."

financial constraints, climate-driven changes in extreme weather patterns, inadequate commonwealth and federal emergency responses, and an electric utility on its last legs struggling to keep power flowing across an electric system on the perpetual verge of collapse. The answer, as we will discover, is: "all of the above, and then some" — a complex web of events spanning from the Spanish American War through the Trump administration. We will argue that compound risks and cascading failures, as well as institutional unpreparedness, are the defining narratives of Hurricane Maria's aftermath.

And second, *what can we do to prevent it from happening again?* As we will review, a substantial body of climate science literature empathically shows that while the exact impact of climate change on hurricanes is still a matter of close study, it is quite clear that the changes underway have already and will continue to exacerbate the risks hurricanes pose to Puerto Rico and the United States. We can expect to see extreme storms that will bring with them stronger winds, higher surges, and longer-lingering rainfall — all of which will be particularly exacerbated for a physically, economically, socially, and infrastructurally vulnerable territory like Puerto Rico.

We are likely to see more storms like Maria threaten Puerto Rico over the coming thirty years. In light of this, the Puerto Rico Electric Power Authority (PREPA) and the commonwealth's government, the U.S. Congress, and the Executive Branch have all taken steps towards dealing with Maria's destructive impact and clarion warning call for the Puerto Rican electric power system. We will consider the process by which resilience has become the watchword of Puerto Rican electricity policy, while also examining the challenges associated with decarbonizing its still quite fragile and heavily fossil fuel-dependent electric system.

We will examine the events of Hurricane Maria and the ensuing outage, before taking a step back to consider the circumstances and events that led to the unprecedented disruption to Puerto Rico's electric power system. We will follow Puerto Rico's financial, political, and electric systems from their colonial origins, through their response to Maria. And we will examine the steps that each is taking at present, in an effort to build a more resilient electric system, that can absorb another Maria-type blow without repeating its devastating aftermath. Finally, we will see how Puerto Rico's electric system fared against a test of its resilience in the years following Hurricane Maria, and consider what Puerto Rico's experience can teach us about resilient decarbonization.

### 3.1.1 Hurricane Maria

On September 12, 2017, the National Hurricane Center (NHC)[78] in Miami, FL began tracking what it referred to as a "well-defined tropical wave" — really, not much more than a band of low pressure — that had developed off the western coast of Africa.

As it moved westward across the Atlantic over the next few days, the wave began producing thunderstorms and organized, swirling bands of clouds. With the growing storm about 580 miles off the coast of Barbados, the NHC upgraded it to a tropical depression[79] at 8 a.m. AST[80] on September 16th, dubbing it "Tropical Cyclone Fifteen." Six hours later, it had strengthened further, becoming the thirteenth tropical storm of the 2017 Atlantic hurricane season. The newly-minted tropical storm was named in accordance with NHC practices, and by noon AST on September 17th, it would strengthen into Hurricane Maria.

Over the course of September 17th and 18th, Maria entered a region of warm sea surface temperatures and favorable wind shear in the Caribbean Sea. This allowed it to rapidly intensify — jumping from a Category 1 hurricane with winds of 74 mph, to a Category 5 hurricane with sustained winds of 165 mph, in less than twenty-four hours.

The storm made landfall on the small Caribbean island nation of Dominica just after 9pm AST on September 18th, damaging 98% of the buildings on the island — including that of the Prime Minister, who had to be evacuated from his residence when it began to flood.

Maria was slightly weakened by its pass over Dominica, but quickly re-strengthened as it angled northwest towards the island of Puerto Rico, reaching its peak wind speeds of around 173 mph around 11pm AST on September 19th.

Over the next few hours, the storm weakened slightly and expanded in size, before finally making landfall in Yabucoa municipality on Puerto Rico's southeastern coast, at 6:15 a.m. AST on September 20, 2017. It moved from southeast to northwest across the island, dropping torrential rain (up to 37 inches in some areas), lashing the coasts with a nine-foot storm surge, and battering structures with fierce winds. Its sustained windspeeds of 155 mph

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[78] The NHC is the National Weather Service's (NWS) hub for Atlantic tropical cyclone forecasting, and is part of the National Oceanographic and Atmospheric Administration (NOAA).

[79] Per the NHC, a tropical depression is a tropical cyclone in which the maximum sustained surface wind speed is 38 mph or less.

[80] Atlantic Standard Time, Puerto Rico's time zone

at landfall (just under Category 5) made Hurricane Maria the strongest storm to strike Puerto Rico since the San Felipe Segundo hurricane of 1928.

Seven hours and forty-five minutes later, Hurricane Maria emerged back into the Caribbean Sea, having slashed a diagonal path of devastation across Puerto Rico's core.[81]

### *The aftermath: impact on Puerto Rico's electric system*

Hurricane Maria was the worst disaster that Puerto Rico had seen in nearly a century. NOAA conservatively estimates that the storm caused more than $90 billion in damages across the island, and took countless lives — in the immediate aftermath, the total was estimated at 64 by the government, with an expectation that the number would dramatically increase.

Beyond the toll to human life and property, the storm also devastated Puerto Rico's electric system, which was already reeling following the blow it sustained during Hurricane Irma.

Irma passed north of the island two weeks before Maria, lashing it with wind, rains, and waves, without making landfall. However, this was enough to cause widespread outages across the island: at the peak of the outage, PREPA reported that 1.1 million of its 1.5 million customers were without power. However, the actual physical damage to the system, while significant, was repaired relatively quickly. The day before Maria struck, PREPA reported that it had successfully restored power to 96% of its customers, leaving just 61,308 without power, as shown in Figure 6.[82] Irma weakened PREPA's already struggling electric system but did not destroy it, leaving it fragile yet functional.

Maria would be a different matter, altogether.

The morning after the storm hit, the Department of Energy's Infrastructure Security and Emergency Response (ISER) division issued this curt assessment of the electric sector in Puerto Rico:

> As of Wednesday afternoon, nearly all 1.57 million electricity customers in Puerto Rico were reported to be without power.[83]

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[81] National Hurricane Center, "Tropical Cyclone Report: Hurricane Maria," 2.

[82] U.S. Energy Information Administration, "Puerto Rico's Electricity Service Is Slow to Return after Hurricane Maria - Today in Energy."

[83] Office of Infrastructure Security and Energy Restoration, "Hurricanes Maria, Irma, and Harvey - September 21 Morning - Event Summary (Report #40)."

That number translated to more than 3.3 million people without power, save the few institutions that had managed to keep the power on with the aid of onsite generators.

The damage to PREPA's electric system across the island was immense — though, that wasn't yet clear. In addition to tearing down power lines, Maria had also knocked out cellphone towers and internet connections — making communication, especially with the island's rugged interior, quite difficult. In total, the storm destroyed 95% of the island's cellphone towers, as well as 85% of the island's telephone and internet lines.[84,85]

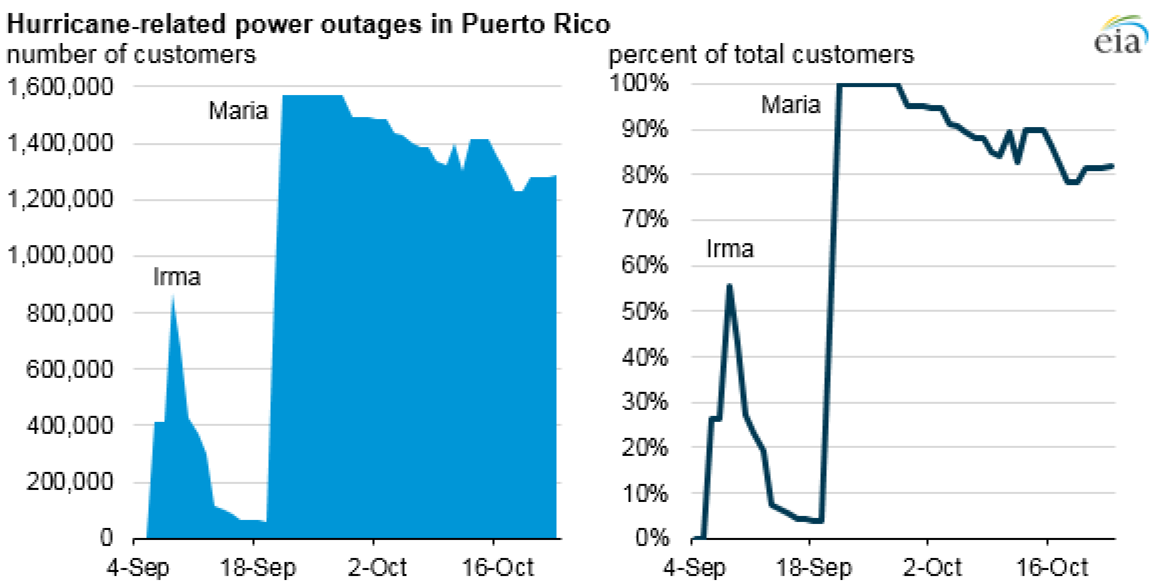


Figure 6. Puerto Rico power outages after Hurricanes Irma and Maria[86]

While it took some time to assess the true extent of the damage to the island's electric system, it was immediately clear that it was catastrophic. Speaking to CNN the day after Maria made landfall, PREPA CEO Ricardo Ramos flatly stated that "the island's power infrastructure had essentially been 'destroyed.'"[87] At the time, Puerto Rico had around 2,478 circuit miles of transmission lines approximately 31,550 circuit miles of distribution lines, and 342 substations.[88] In the aftermath of the storm, the best estimates offered by Ramos

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[84] Deibert, *When the Sky Fell: Hurricane Maria and the United States in Puerto Rico*, 70 (digital).
[85] Scott, "Hurricane Maria's Devastation of Puerto Rico."
[86] U.S. Energy Information Administration, "Puerto Rico's Electricity Service Is Slow to Return after Hurricane Maria - Today in Energy."
[87] "Hurricane Maria Updates."
[88] Fisher and Horowitz, "Expert Report: State of PREPA's System," 136, 140.

and by the U.S. Army Corps of Engineers were that somewhere around 80% of distribution lines had been damaged, along with somewhere between 80 and 100% of transmission lines.[89,90]

As Figures 6,7, and 8 (generated by reviewing of 131 situation reports[91,92] from the U.S. Department of Energy) demonstrate, it was clear from the outset that the island's road to electric system restoration would be a slow one. The entire island was without power for eight full days after the storm, at which point PREPA crews began making initial efforts to reconnect areas near the utility's major generation facilities.

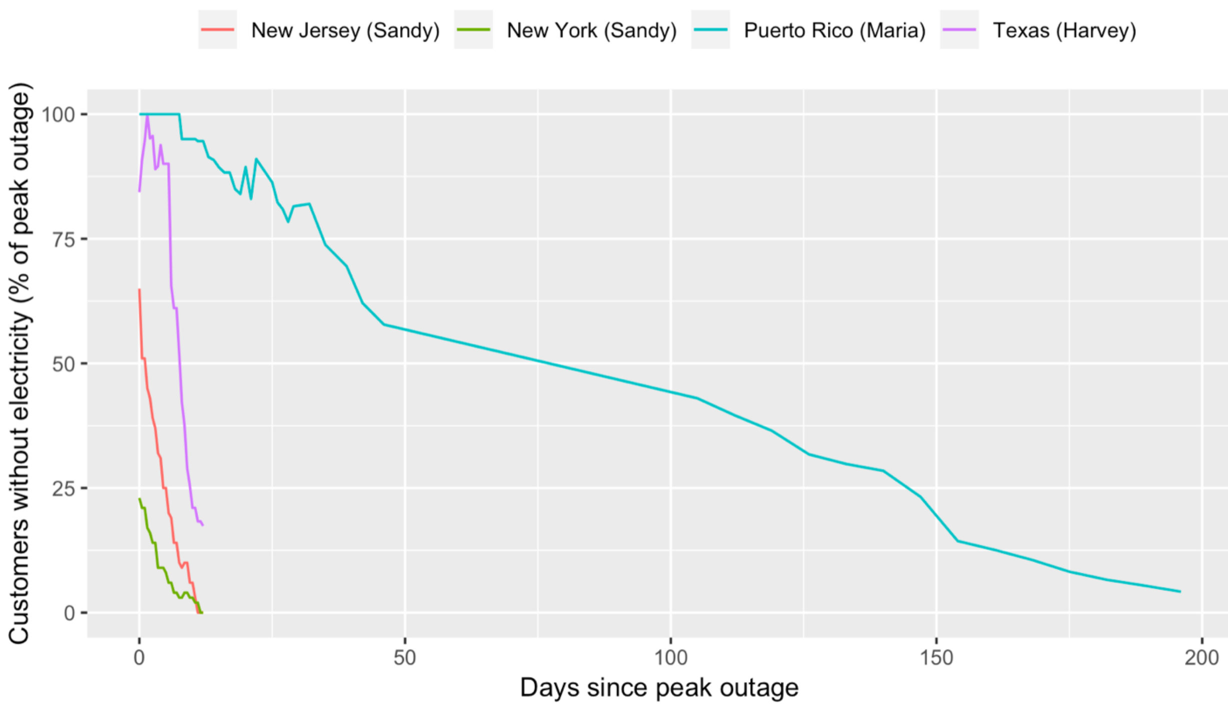


Figure 7. Electric recovery from hurricanes — Sandy, Harvey, Maria (%)[93]

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[89] Campo-Flores, "Puerto Rico's Power Restoration Slowed by Miles of Downed Lines."
[90] U.S. Department of Defense, "Army Committed to Restoring Puerto Rico's Power."
[91] Office of Cybersecurity, Energy Security, and Emergency Response, "Hurricanes Nate, Maria, Irma, and Harvey Situation Reports."
[92] Office of Cybersecurity, Energy Security, and Emergency Response, "ISER - Hurricane Sandy."
[93] Note: Puerto Rico outage data from days 47-104 are interpolated, as PREPA stopped providing data to the Department of Energy.

But even once the restoration process began making progress, it was often halting — the data in the two figures, taken from daily situation reports issued by ISER until April 2018, reveals that the system remained quite unstable through the first month of the restoration process, with transmission line failures and generator trips plunging thousands who had just had power restored to them back into darkness.

In the end, it would take until March 28, 2018 — 189 days, or just over 6 months — for power to be restored to 95% of PREPA's customers. And there would be a long tail for the remaining roughly 80,000 customers. PREPA would not declare that service had been fully restored to 100% of its customer base until August 14, 2018 — 328 days, or nearly 11 months after Maria made landfall.[94]

The most striking element of the post-Maria blackout is undoubtedly its length and size. At 3.4 billion customer-hours long as of April 2018, it was the largest power outage in U.S. history by more than a factor of three. In fact, it was responsible for more customer-hours of power outages than all other outage events in the U.S. over the preceding five years, combined.[95] And even in comparison to the aftermath of other major hurricanes, the extreme length of the post-Maria restoration is immediately apparent.

After Superstorm Sandy in 2012, an event we will discuss extensively in Chapter 3.3, power was restored to 95% of customers in New Jersey within 10 days, and New York within 7 days — with the hardest-hit regions of Long Island experiencing outages of up to two weeks. It's worth noting that Sandy made landfall with the strength of a Category 1 hurricane when it struck the New York/New Jersey region, while Maria's windspeeds were just under Category 5 strength when it struck Puerto Rico.

However, even if we consider the data from Hurricane Harvey, a Category 4 hurricane which hit Texas just weeks before Maria struck Puerto Rico, we find an equally discordant note. Harvey caused $125 billion in damage, largely concentrated in the Houston metropolitan area, which is home to nearly 7 million people — more than double the population of Puerto Rico. However, at the peak, less than 4% of Texas's electric customers lost power (even though the Houston metropolitan area accounts for roughly 24% of the

[94] Campbell, "It Took 11 Months to Restore Power to Puerto Rico after Hurricane Maria. A Similar Crisis Could Happen Again."

[95] Houser and Marsters, "The World's Second Largest Blackout."

state's population), and even the hardest-hit parts of Houston had their power fully restored within 14 days.

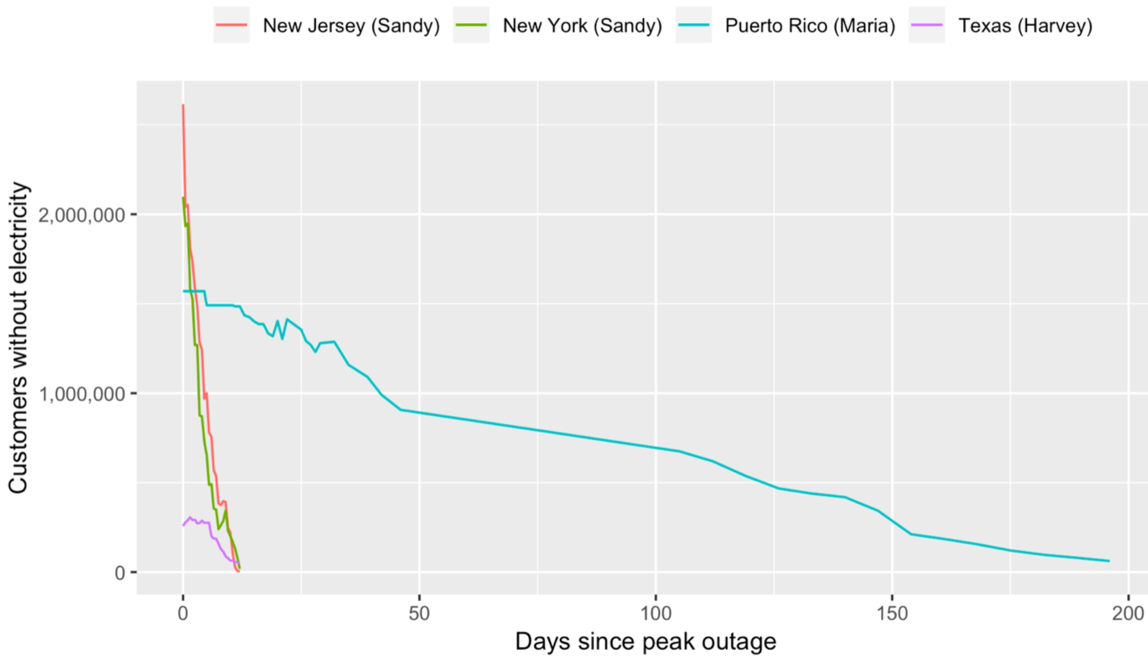


Figure 8. Electric recovery from hurricanes — Sandy, Harvey, Maria (customers)[96]

For comparison, we also note in Figure 8 that that the total number of customers who lost power after Maria was significantly higher during Superstorm Sandy, as New Jersey had roughly 1 million more customers lose power, and New York roughly 500,000 more — to say mothing of the roughly 4 million other customers across the East Coast who were also affected by the storm.

The impact of the unprecedented outage caused by Maria would have been a body blow to any community, but it struck Puerto Rico's population — which has among the highest levels of socioeconomic vulnerability in the U.S. — particularly hard.

Puerto Rico's poverty rate stood at 44.4% in 2017, compared the national rate of 12.3%. For context, Puerto Rico's poverty rate was more than double that of Mississippi (19.8%), the

[96] Note: Puerto Rico outage data from days 47-104 are interpolated, as PREPA stopped providing data to the Department of Energy.

state with the highest poverty. The median household income was $20,078 in 2016, less than half that of the lowest-ranked state, Mississippi ($41,754).

It has also had historically higher unemployment levels than the rest of the United States, and was hit particularly hard in the aftermath of the financial crisis and Great Recession. Puerto Rico's unemployment rate peaked at 17% in May 2010, while the nationwide peak during the crisis was 10%. Even after the recovery, unemployment still stood at 11.8% in 2016, vs. 4.9% nationally.

This comes as no surprise in the context of the commonwealth's broader socioeconomic troubles. While the U.S. as a whole experienced its longest period of continuous economic growth from June 2009 until the COVID-19 pandemic in March 2020, Puerto Rico has been in a recession essentially since 2005, with negative annual GDP growth every year save a 0.03% increase in 2012. At the same time, the island's population has continuously declined, falling by 16.4% since 2005.

The most tragic example of how Puerto Rico's existing vulnerability compounded the impacts of Maria and the blackout comes in the form of the disaster's still-debated death toll.

Initial estimates by the Puerto Rican government put the death toll at 64, though officials openly admitted that this was almost certainly a gross undercount. In August 2018, researchers at the George Washington University's Milken Institute School of Public Health — working under a commission from the Governor of Puerto Rico — calculated that the island had seen 2,975 excess deaths for from September 2017 through February 2018, with a 95% confidence range of 2,658-3,290.[97]

The strange formulation of their conclusion — "excess deaths" within a 95% confidence range — stems from the fact that Puerto Rico's medical system was simply overwhelmed in the aftermath of the storm. While they found that most of the deceased were properly certified by medical professionals, the researchers nevertheless were only confident in their methodology's ability to calculate excess mortality — a grim reminder that we may never know, causally, the exact number of Americans who died as a result of Hurricane Irma.

While we must rely on the GWU researchers' best estimate for the total number of deaths, a look at Figure 9 (taken from their published report), reveals two of sobering trends.

[97] Milken Institute School of Public Health, "Ascertainment of the Estimated Excess Mortality from Hurricane Maria in Puerto Rico," 9.

First, we see a clear element of socioeconomic stratification in the rates of excess mortality. While the top and middle third of the island's socioeconomic spectrum both saw excess mortality rates ranging from 5-30% above normal, that range was much higher for those in the bottom third of the spectrum: 25-65%. Moreover, at the peak of the post-Maria "excess mortality" event, nearly 40% more Puerto Ricans were being reported dead from the bottom third of the socioeconomic spectrum, than from the top third.

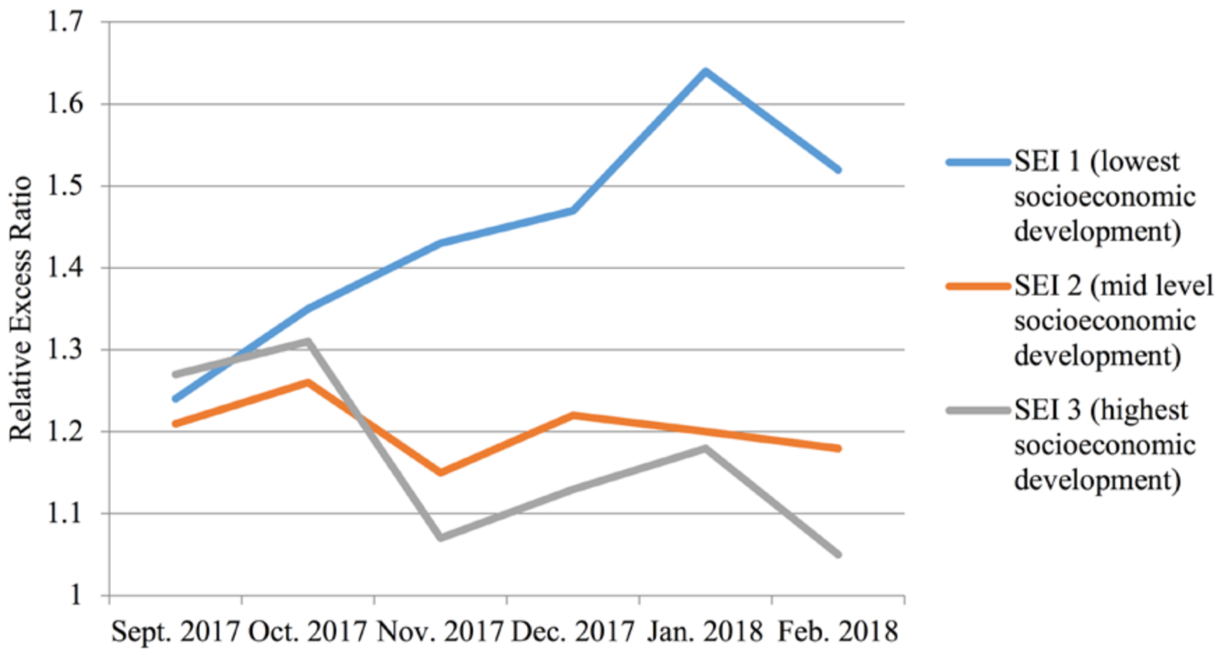


Figure 9. Estimated relative excess mortality from Hurricane Maria in Puerto Rico, by socioeconomic level[98]

Second, we note that while the rate of excess mortality spiked in the month after the storm for all three socioeconomic strata, it leveled off/declined for the top and middle thirds of the population, while steadily climbing through January 2018 for the lowest-ranked third of the population. Even after peaking at 65% above the normal mortality rate, the February estimate for excess mortality among those in the bottom third of Puerto Rico's socioeconomic spectrum remained at nearly 50%. This suggests that a significant fraction — perhaps a majority — of the excess deaths that occurred in the wake of Hurricane Maria might have been driven more by the prolonged blackout — with its attendant impacts on medical

[98] Milken Institute School of Public Health, 10.

facilities, food, water, and residential comfort — than by the physical damage caused by the hurricane itself.

Having examined the catastrophic damage that Maria inflicted on Puerto Rico and its electric system, and the tragic loss of life that followed, we now turn our attention to a simple question with a number of complex answers: why did this happen? What were the underlying drivers that contributed to this unprecedented humanitarian and infrastructural catastrophe?

### 3.1.2 Underlying drivers of the blackout

We will examine four underlying drivers of the catastrophic blackout that followed Hurricane Maria: the impact of climate change on hurricanes like Maria; Puerto Rico's long-running financial troubles; the challenges that PREPA was struggling to grapple with even before the storm, and the numerous challenges that emerged during the response effort itself.

#### *Climate change and Atlantic hurricanes in Puerto Rico*

The year 2017 saw the highest average ocean temperatures[99] in recorded human history — a title that would subsequently be claimed by 2018, and then by 2019. These are just the latest data points in a sharply increasing trend in global ocean temperatures that has been evident in the observational record since at least the late 1980s, as shown in Figure 10. As a result, every year of the past decade ranks among the top ten warmest on record for the global ocean.

This trend is part of the evidence underlying a growing, but still hotly-debated, research consensus supporting the idea that anthropogenic emissions have driven, and will continue to drive, an increase in Atlantic hurricane activity.

The NCA reports that "there is broad agreement that human factors have had an impact on the observed oceanic and atmospheric variability in the North Atlantic, and there is medium confidence that this has contributed to the observed increase in hurricane activity since the 1970s." While there is low confidence as to what impact ongoing climatic trends will have on the frequency of intense Atlantic hurricanes in the years to come, the NCA asserts that it is likely that the intensity — maximum wind speeds and precipitation — of tropical cyclones and hurricanes will increase on average, globally, over the coming decades.[100]

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[99] Measured as heat content in the top 2000m of the ocean
[100] U.S. Global Change Research Program et al., "Climate Science Special Report," 257–59.

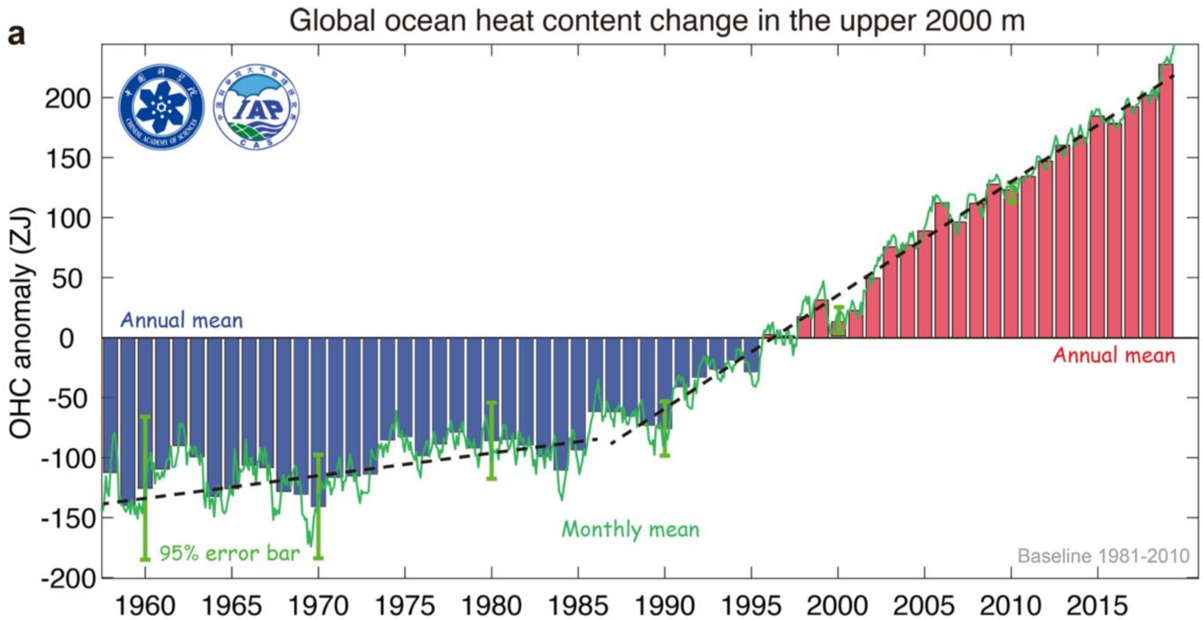


Figure 10. Change in global ocean heat content, 1955-2019.[101]

Maria's extreme impacts offer a glimpse at what those trends could mean for particularly vulnerable regions, including small Caribbean islands like Puerto Rico. A review of historical rainfall data reveals that of the 129 storms that have hit Puerto Rico since 1956, Maria resulted in the highest island-wide average rainfall, as well as record peak rainfall of up to 37 inches. However, based on current trends in atmospheric and ocean surface temperatures, an extreme-value analysis found that the likelihood of future storms bringing Maria-caliber rainfall has increased nearly fivefold, relative to 1956.[102] The NCA concurs with that assessment, specifically noting that even when taking current uncertainties surrounding the link between climate change and hurricane patters into account, "climate models project an increase in the frequency of strong hurricanes (Categories 4 and 5) in the Atlantic Basin, including the Caribbean."

The expected increase in Maria-caliber hurricane activity doesn't bode well for Puerto Rico. As the NCA notes, the island's current demographic and economic challenges — as well as the fact that it is an island, isolated from the rest of the U.S. — "impos[e] greater burdens

[101] Cheng et al., "Record-Setting Ocean Warmth Continued in 2019," 138.

[102] Keellings and Ayala, "Extreme Rainfall Associated With Hurricane Maria Over Puerto Rico and Its Connections to Climate Variability and Change."

in terms of response and recovery compared to many places in the continental United States."[103]

### *The other storm: Puerto Rico's financial crisis*

Over the past decade, Puerto Rico has been wracked by financial crisis after financial crisis: from the loss of its manufacturing industry, to an ongoing debt crisis. Together, the commonwealth's financial troubles have undermined its institutions' capability to deal with major exogenous challenges like the aftermath of Hurricane Maria.

To truly understand Puerto Rico's modern financial troubles, we must first revisit a few key pieces of legislation that laid the foundation for the modern U.S.-Puerto Rico relationship.

Following the Spanish-American War, Puerto Rico's first civilian government under U.S. territorial rule was established by the Organic Act of 1900. Also known as the Foraker Act, the law exempted the territory from most federal taxation, while giving it the power to levy taxes and issue public debt in the form of bonds.[104]

The Puerto Rican Federal Relations Act of 1917, commonly known as the Jones-Shafroth Act, built on the Foraker Act. It granted U.S. citizenship to all Puerto Ricans, and established an executive branch and bicameral legislature for the territory. It also contained this key passage, which has arguably been among the most impactful on the trajectory of Puerto Rico's economy, after citizenship:

> …all bonds issued by the government of Porto Rico, or by its authority, shall be exempt from taxation by the Government of the United States, or by the government of Porto Rico or of any political or municipal subdivision thereof, or by any State, or by any county, municipality, or other municipal subdivision of any State or Territory of the United States, or by the District of Columbia.[105]

[103] U.S. Global Change Research Program et al., "Impacts, Risks, and Adaptation in the United States," 840, 845.
[104] Organic Act of 1900.
[105] Puerto Rican Federal Relations Act of 1917.

This is what has come to be known as the “triple tax-exemption,” a quirk of federal law which means that Puerto Rican public debt — issued by the Commonwealth’s government, public corporations (like PREPA), or one of its 78 municipalities[106] — is exempt from federal, state, and local taxes, regardless of where in the U.S. the bondholder lives. While income earned from municipal bonds is generally exempt from federal income taxes, the exemption from state taxes usually only applies to bonds that are issued in that particular state. This means that Puerto Rican bonds, which benefit from a nationwide triple tax-exemption thanks to the Jones-Shafroth Act, were very attractive to fixed-income investors looking to enhance their profit margins.

Just three years later, the same Senator Wesley Jones would lead the passage of the Merchant Marine Act of 1920 (confusingly known as the Jones Act). Among other provisions, the Act requires that all goods shipped by boat between ports within the U.S. be carried on U.S. flagged ships, which are constructed in the U.S., owned by U.S. citizens, and crewed by U.S. citizens and/or permanent residents. This would come to prove quite burdensome for an island U.S. territory like Puerto Rico, which is almost entirely dependent on imports — especially when it comes to fuel for its fossil-fueled electric generators, and the kinds of specialized electric system equipment it would find itself needed to replace *en masse* in the wake of Hurricane Maria.

The next major legislative component of Puerto Rico’s financial evolution came in 1976, with the passage of Section 936 of the Internal Revenue Code. While the federal government had long used tax policy to try and incentivize commerce, manufacturing, and other business activity between the mainland U.S. and the territories, §936 took that effort to a new level. The provision exempted all income earned by U.S. corporations through activities based primarily in Puerto Rico and the territories from federal corporate income taxes, and made the income deductible from Puerto Rico’s corporate income tax.[107] This was extremely attractive to American companies, particularly those in the pharmaceutical and manufacturing sectors, and the island’s economy boomed.

However, by the 1990s, §936 had come to be viewed as a loophole for tax-evading corporations. In 1996, President Clinton signed a 10-year phase out of the provision into law,

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[106] Unlike U.S. states, Puerto Rico does not have county-level divisions, but is rather divided into 78 municipalities.

[107] Puerto Rico And Possession Tax Credit [Repealed].

which would completely eliminate it by the end of 2005.[108] The impact on Puerto Rico's economy was readily apparent. One study found that manufacturing wages across Puerto Rico dropped by 16.7% from 2005 to 2012 as a result of the §936 phaseout, while reducing the number of manufacturing establishments in the commonwealth by between 18.7% and 28.0% over the same period.[109]

The economic decline coincided with a ramp up in debt spending by Puerto Rico's government. Since a 1974 executive opinion on a quirk in the constitution's balanced budget amendment, the commonwealth's government had routinely issued bonds in order to raise funds needed to balance Puerto Rico's budget. This essentially meant that the commonwealth was constantly borrowing money to fund its operating budget — a practice that the U.S. Government Accountability Office has described as "unusual" and a "red flag" for credit ratings agencies. By the end of 2005, Puerto Rico had roughly $35 billion in outstanding bonded debt. However, that number would spike over the next decade. In 2006, the government created a new financing mechanism backed by a newly-implemented sales tax, that essentially allowed it to issue more bonds, in order to raise funds to pay off its existing bonds.[110]

Combined with an increased reliance on the issuance of debt to finance its operations after the phase out of §936, this left Puerto Rico with nearly $70 billion in debt by 2015 — roughly the same amount as its GNP. At the same time, the costs of servicing all this debt had grown to more than $5 billion annually by 2014, equal to over 15% of the commonwealth's total revenue. Facing choices between basic services and servicing its growing debt burden, Puerto Rico missed a scheduled bond payment in August 2015, and subsequently defaulted on more than $1.5 billion in debt. By the end of 2016, Puerto Rico owed roughly $40.8 billion in primary government debt, and $24.3 billion in debt for its publicly owned corporations — including $9.1 billion for PREPA. It also separately owed $44.9 billion in unfunded pension liabilities, for a total of nearly $110 billion in outstanding debt.[111,112]

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108 Greenberg and Ekins, "Tax Policy Helped Create Puerto Rico's Fiscal Crisis."

109 Feliciano and Green, "US Multinationals in Puerto Rico and the Repeal of Section 936 Tax Exemption for U.S. Corporations."

110 U.S. Government Accountability Office, "Puerto Rico: Factors Contributing to the Debt Crisis and Potential Federal Actions to Address Them," 22–24.

111 U.S. Government Accountability Office, "U.S. Territories: Public Debt Outlook – 2019 Update," 9.

112 U.S. Government Accountability Office, "Puerto Rico: Factors Contributing to the Debt Crisis and Potential Federal Actions to Address Them," 14.

The U.S. has a long history of putting in place protections to ensure that government organizations are able to seek protection in the face of crippling financial troubles and debts, like those faced by Puerto Rico. And while state governments cannot file for bankruptcy, their constituent agencies, publicly-owned corporations, and municipalities can, by seeking protection under Chapter 9 of the U.S. Bankruptcy Code, which has existed in various forms since the Great Depression. However, in an as-yet unexplained quirk of legislative history, Senator Strom Thurmond added an amendment to an obscure 1984 bankruptcy reform bill that specifically singled out Puerto Rico and Washington, D.C., and their constituent entities, as ineligible for Chapter 9 bankruptcy protection — a protection that had been available to them up to that point.[113,114] This meant that thirty years later, as Puerto Rico and its public corporations (including PREPA) teetered on the verge of defaulting on their debts, they were unable to avail themselves of the Chapter 9 bankruptcy protections available to nearly every other U.S. state and territory.

In response to this precarious situation, Congress passed the Puerto Rico Oversight, Management, and Economic Stability Act (PROMESA), which was signed by President Obama in June 2016.[115] The Act placed a halt on the onslaught of legal claims being filed against Puerto Rico by, among others, hedge funds that had bought copious amounts of Puerto Rican debt on the municipal bond market at extremely low prices, with the hopes of extracting profits via litigation — referred to derisively in Puerto Rico as "vulture funds," for a perceived similarity to vultures circling a wounded animal.[116]

In the place of the existing legal process, PROMESA created a Financial Oversight and Management Board (FOMB) — a seven-member, presidentially-appointed commission with sweeping power to oversee Puerto Rico's fiscal affairs, and to facilitate the resolution and restructuring of its debts. It also created two processes for debt resolution — Title III, similar to Chapter 9 municipal bankruptcies, and Title VI, a form of arbitrated negotiation between the debtors and the creditors.[117] The commonwealth's government entered a Title III quasi-bankruptcy proceeding in May 2017, and PREPA followed it in July 2017.

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113 Bankruptcy Amendments and Federal Judgeship Act of 1983.
114 Greenberg, "Mystery: Strom Thurmond, Puerto Rico and Bankruptcy Protection."
115 Wicker, Puerto Rico Oversight, Management, and Economic Stability Act (PROMESA).
116 Barron, "The Curious Case of Aurelius Capital v. Puerto Rico."
117 U.S. Government Accountability Office, "U.S. Territories: Public Debt Outlook – 2019 Update," 10.

In addition to claims of predatory behavior by "vulture funds," Puerto Rico's debt crisis has spawned numerous accusations of wrongdoing and manipulation against financial and consulting companies.

In March 2019, one of the leaders of Swiss bank UBS's Puerto Rico operations was sentenced to a year in prison for bank fraud, after he was convicted of convincing customers to take out credit lines in order to buy into UBS's Puerto Rican municipal bond funds that ultimately lost over $1 billion in value — and then pocketing the commissions. While Ramirez maintains that he is being scapegoated for a larger effort to push the bond funds that was prevalent across UBS Puerto Rico, both the bank and the federal prosecutors for the case maintain that this is untrue. However, in 2015, UBS paid $34 million to settle charges brought by U.S. Securities and Exchange Commission (SEC) and the Financial Industry Regulatory Authority (FINRA), surrounding its failure to properly supervise Ramirez.[118] According to CNBC, UBS had paid nearly $480 million in additional FINRA settlements to clients as of January 2019, with more than 800 cases still pending at the time.[119]

Meanwhile, global management consultancy McKinsey & Company — which is slated to earn more than $1 billion for its work supporting the FOMB and Puerto Rico's financial restructuring plans — has faced accusations that it has led the Board to prioritize the interests of holders of Puerto Rico's debt over those of its population, by pushing for financial austerity measures. [120] The firm has also been accused of having conflicts of interest, after it was disclosed that one of its in-house retirement funds owned at least $20 million in Puerto Rican bonds.[121]

In response, McKinsey has noted that while it provides advice to the FOMB, the Board has the ultimate decision-making power  The firm has also insisted that its investments are wholly independent from its consulting operations — and it's important to note that there has been no formal finding of wrongdoing on McKinsey's part. However, the firm reached a $15 million settlement with the U.S. Department of Justice in 2019, to resolve an investigation into similar allegations that it failed to disclose conflicts of interest while

[118] U.S. Securities and Exchange Commission, "SEC Charges UBS Puerto Rico and Two Individuals in Actions Relating to Former Broker's Fraud."
[119] Giel, "Ex-UBS Broker Sentenced in Fraudulent Puerto Rico Bond Sales Scheme."
[120] Rice, "The McKinsey Way to Save an Island."
[121] Walsh, "McKinsey Advises Puerto Rico on Debt. It May Profit on the Outcome."

advising bankruptcy proceedings, in an unrelated case. The firm did not admit fault as part of the settlement.[122]

Questions of external impropriety aside, Puerto Rico appears to be slowly emerging from under the burden of its crippling debt. In the four years since PROMESA was passed, Puerto Rico has managed to restructure what had become $74.7 billion in general debt and $54.5 billion in pension liabilities, securing a 33% reduction in the overall debt, including a 27% reduction in PREPA's debt burden from $10.1 billion to $7.4 billion.[123]

While Puerto Rico appears to be making progress towards reducing its long-running financial troubles, they appear to have severely undermined its institutions in the meantime — particularly PREPA.

### *Challenges facing PREPA and Puerto Rico's electric system*

Long before Hurricane Maria made landfall, the Puerto Rico Electric Power Authority and its ailing, island-wide electric system faced deep, pressing challenges. As one expert report to PREB put it: "PREPA's system today is in a state of crisis."[124]

As of 2016, the Puerto Rico Electric Power Authority was the largest public power utility in the United States in terms of total customers, had the third-highest gross revenues, and generated the ninth-most energy.[125] It was formed in the 1941 as the Puerto Rico Water Resources Authority, under the pre-WWII U.S. government. It consisted largely of hydroelectric dams, the main source of electric generation at the time.

Today, PREPA's electric system is built around eight large fossil-fueled power plants, shown in Figure 11, most of which are more than forty years old. Four of the plants, including the three largest ones, run on heavy fuel oil, along with either natural gas or diesel fuel. Four of the plants rely on diesel to some degree, while two are powered at least in part by natural gas, and one by coal. Given Puerto Rico's lack of natural fossil fuel resources, essentially all of the fuel for these plants — oil, diesel, natural gas, and coal — must be shipped to the island by boat. This supply chain is not only fragile, but also expensive. The costs stem from both the inherent expenses of long-distance marine shipping, as well as the additional constraints

122 Walsh, "McKinsey Will Return $15 Million in Fees Over Disclosure Failures."
123 Walsh and Russell, "$129 Billion Puerto Rico Bankruptcy Plan Could Be Model for States."
124 Fisher and Horowitz, "Expert Report: State of PREPA's System," 26.
125 American Public Power Association, "Public Power: 2018 Statistical Report."

imposed by the Jones Act, which limit the acceptable range of vessels, operators, owners, and crew that can be used to carry goods to Puerto Rico.

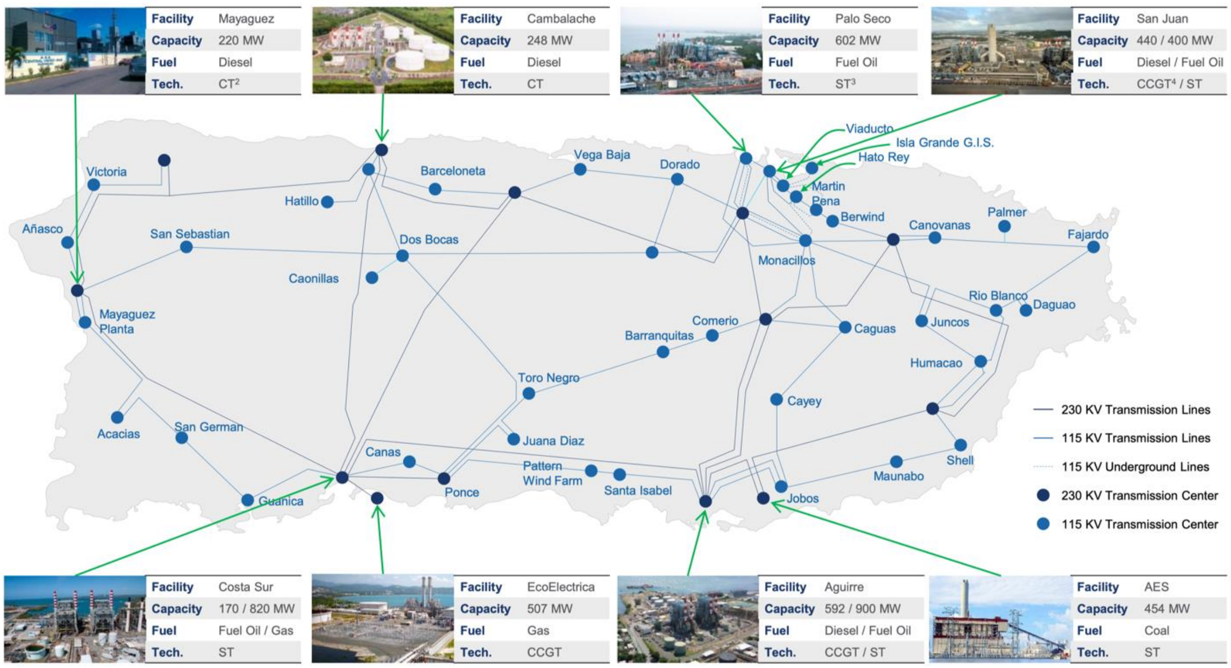


Figure 11. PREPA generation and transmission system, 2019[126]

As we can see in Figure 11, PREPA's electric system relies heavily on large, centralized generation plants, and the distribution of those plants has a strong geographic asymmetry. Around 70% of Puerto Rico's generation capacity is located on the southern coast, while 70% of the island's population are located on the northern coast. This means that electricity must be transmitted across the island's mountainous and difficult-to-access interior. The task of moving that electricity falls to PREPA's 2,478 circuit miles of transmission lines, 31,550 miles of distribution lines, and 333 substations (as of the 2016 report).[127] Maria's truly devastating impact on the electric system was cutting the key transmission arteries that run north/south across the island, connecting its coastal population centers with its generators. This meant that restoration would have to involve replacing transmission lines across the island's mountainous interior.

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[126] Puerto Rico Electric Power Authority, "2019 Fiscal Plan for the Puerto Rico Electric Power Authority," 35.
[127] Fisher and Horowitz, "Expert Report: State of PREPA's System," 137,141.

But even a year before Maria, PREPA's electric system was already in dire trouble, driven by its financial challenges. As the Synapse report put it "the political reality of avoiding cost increases" repeatedly took priority over the actual needs of PREPA's electric system — driven by the fact that Puerto Rico already has the third-highest retail, industrial, and commercial costs of electricity in the U.S., trailing only Hawaii and Alaska. The U.S. Government Accountability Office (GAO) notes that the utility hasn't raised its base rate for electric service since 1989 — instead choosing to finance its operations through the issue of the more than $10 billion in debt that sent the utility into a Title III quasi-bankruptcy proceeding under in July 2017, just months before Maria made landfall.[128]

The impact of these financial constraints on PREPA's electric system has been swift and brutal. The expert report to PREB, produced by Cambridge, MA-based consultancy Synapse Energy Associates, asserted that PREPA's "generation and transmission infrastructure [were] literally falling apart."[129] The report laid out a number of operational challenges the utility was facing on an ongoing basis, noting that the number of outages experienced by the average PREPA customer was "four to five times higher" than the average mainland customer — and that the rate was steadily increasing.[130] By the end of 2015, the amount of generation lost at three key PREPA plants, as a result of unplanned outages, exceeded the amount of electricity they were actually producing.[131] The Synapse report traces the root of PREPA's problems to a single primary source: its financial difficulties. The report notes that:

> PREPA, by every measure, operates in a deeply cost-constrained environment. Limited access to capital markets, political pressure to sustain low rates, and a constrained economy have led to PREPA having relatively sparse working funds.[132]

As a result of these constraints, the report argues, PREPA has been forced to make dramatic reductions in its maintenance operations — moving to an essentially reactive posture — and slash its workforce.

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[128] U.S. Government Accountability Office, "Puerto Rico: Factors Contributing to the Debt Crisis and Potential Federal Actions to Address Them," 25.
[129] Fisher and Horowitz, "Expert Report: State of PREPA's System," 26.
[130] Fisher and Horowitz, 14.
[131] Fisher and Horowitz, 27.
[132] Fisher and Horowitz, 14.

PREPA's operations and maintenance budget, as well as investment budget, were dramatically reduced from 2010 to 2016 — including a decrease of more than a third, nearly $100 million, in its capital budget. Per the Synapse assessment, that decrease in spending on maintenance and capital investments "tracked PREPA's reduced reliability almost in lockstep."[133] At the same time, the utility also lost an estimated 22% of its workforce from 2014-2016 alone, with the losses consisting largely of "PREPA's most experienced staff, and those able to make the system work on historically thin budgets."[134]

Per the Synapse report, the resultant "level of disrepair or operational neglect at PREPA's generation facilities" is "difficult to overstate." This stems from the "self-defeating practices" the utility has been forced to adopt as a result of its financial troubles, including pushing off maintenance work, discontinuing overtime pay (and thus extending outages), and spending the majority of its capital budget on repairing its existing infrastructure functional — as opposed to much-needed system upgrades. Over half of the utility's FY 2017 budget was spent on maintenance for its transmission system, while crucial maintenance on some of its petroleum-fueled generation plants have been repeatedly delayed in the hopes that a long-awaited conversion to gas will finally occur.[135]

The financial challenges PREPA faced, and the resulting impacts on its electric system, were further compounded by the utility's own management missteps. In interviews, PREPA's own operational staff admitted that the utility had a bloated and inefficient bureaucracy, with "the equivalent of more than a third of its entire capital budget" being spent on administrative expenses — all while the utility failed to maintain records or record keeping systems that were capable of tracking its capital projects.[136]

Interestingly, few of these are new concerns. Per the GAO, a 1982 assessment by the Department of Energy noted that "the system experiences reliability problems because of its isolation, the large size of several units relative to total system size, limited quick response capability, and maintenance problems."[137] Isolation, centralization, and insufficient maintenance were the same challenges that PREPA faced in the years leading up to Maria, with the financial crunch serving to compound them.

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133 Fisher and Horowitz, 15,69.
134 Fisher and Horowitz, 27,34.
135 Fisher and Horowitz, 18,28,30,33,139.
136 Fisher and Horowitz, 16.
137 U.S. Government Accountability Office, "2017 Hurricane Season: Federal Support for Electricity Grid Restoration in the U.S. Virgin Islands and Puerto Rico," 15.

While PREPA struggled to keep the lights on, Puerto Rico's government made some efforts to push for reforms and set a new direction for the electric system. The commonwealth first implemented a Renewable Portfolio Standard in 2010, which was later tightened to require that renewable generation account for 20% of PREPA's total generation by 2022, 40% by 2025, 60% by 2040, and 100% by 2050.

And in 2014, Puerto Rico's legislative assembly passed Act 57, which required PREPA to produce Integrated Resource Plans (IRPs), which would detail the utility's intended investments in its electric system over the next twenty years. The Act mandated that the IRPs be submitted every three years, beginning in 2016. In 2017, the Puerto Rico Electric Board (PREB) — PREPA's regulator — accepted the IRP with substantial modifications. The next IRP was scheduled to be submitted in 2018, but the process was interrupted by Hurricanes Irene and Maria. That IRP was finally submitted in June 2019, and the PREB's review of the plan remains ongoing — it was once again interrupted by the January 2020 earthquakes, which severely damaged the Costa Sur power plant.

Puerto Rico's financial difficulties played a key role in exacerbating the challenges facing PREPA's already weakened institutional capacity, and its ailing electric system. This would become painfully clear in the response to the blackout caused by Hurricane Maria.

### ***Challenges in the response to the blackout***

The response to Hurricane Maria and the ensuing blackout has become the subject of enormous controversy in the subsequent months and years — a political maelstrom that rivals the storm itself. While establishing definite fault is beyond the scope of our examination of the response, we can say with certainty that the challenges that the response effort faced played a significant role in exacerbating the length and severity of the blackout. These challenges included missteps by PREPA and the Puerto Rican government, as well as a number of controversial decisions on the part of the U.S. federal government.

In the immediate aftermath of major storms, electric utilities commonly call on their peers for what is known as "mutual assistance" — a practice by which utility crews and equipment from other regions flood into the affected service area, to help restore power. However, in the aftermath of Maria, it would take PREPA nearly six weeks to make a request for mutual assistance.[138] Part of the reason for this action was that utilities requesting mutual assistance customarily pay a substantial portion of the cost of the assistance received up front — roughly $25 million, in this case — which PREPA CEO Ricardo Ramos later argued the utility likely would not have been able to pay. Instead, six days after Maria made landfall, the utility turned to a tiny Montana company named Whitefish Energy Holdings, which promised much lower upfront costs, awarding it a $300 million no-bid contract to restore the electric system.

This decision was met with immediate controversy for a number of reasons. Whitefish had only two full-time employees, and relied heavily on subcontractors. Its total revenue for the preceding year had reportedly been just over $1 million. And it had a number of eyebrow-raising ties to the Trump Administration: it was headquartered in the hometown of U.S. Secretary of the Interior Ryan Zinke and led by a close acquaintance of his, while one of its funders was a major donor to President Trump. The contract came under blistering scrutiny both from Puerto Rican officials, as well as from the Federal Emergency Management Agency (FEMA), which reportedly threatened not to cover its costs, citing improprieties in the contracting process. By the end of October, the contract had been cancelled By Governor Rosselló amidst the controversy. A month later, Ramos — who had justified the decision to choose Whitefish over mutual assistance — resigned.[139]

The controversy surrounding Whitefish and electric restoration emerged against the backdrop of a nasty battle over the federal government's broader response to the storm. Tat the time, the bulk of the public controversy focused on President Trump's bizarre public actions in the aftermath of the storm. These ranged from giving himself an "A+" for federal response efforts before the damage was even clear, going on Twitter tirades against Puerto Rican officials and alleged corruption,[140] promoting conspiracy theories suggesting that the death toll had been inflated by his Democratic political opponents,[141] and his only trip to the island — which lasted just five hours, and produced the unforgettable visual of the President throwing paper towels into a crowd of hurricane survivors.[142] Taken together with numerous

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138 U.S. Government Accountability Office, 15.

139 Deibert, *When the Sky Fell: Hurricane Maria and the United States in Puerto Rico*, 142-3,158 (digital).

140 Graham, "Trump Takes to Twitter as Puerto Rico's Crisis Mounts."

141 Stewart, "Trump Restates Puerto Rico Death Toll Conspiracy."

142 Deibert, *When the Sky Fell: Hurricane Maria and the United States in Puerto Rico*, 144-146 (digital).

reports of delays in providing federal aid to Puerto Rico in the aftermath of the storm, the actions of the President and the administration were viewed by many as evidence of a politically motivated delay.[143,144] That said, corruption has posed a challenge in Puerto Rico, with several reports of misappropriated aid funds and supplies emerging in the months and years since — including one that helped bring down Governor Rosselló's administration.[145]

Even setting aside the President's actions, independent research has demonstrated clear disparities between the federal response to Hurricane Maria, when compared to its responses to comparable storms that hit the U.S. mainland in 2017, like Hurricanes Harvey and Irma. Researchers found that even after correcting for geographic factors, the federal response to Maria was not proportional to the severity of the storm or the impact on Puerto Rico's population — especially when compared in terms of funding and staffing to the responses to Harvey and Irma.[146] Even today, the full amount of aid appropriated to Puerto Rico by Congress after Maria has yet to be released by the administration, citing concerns about corruption. In January 2020, it reluctantly released roughly $16 billion, following the earthquakes that struck the island, but attached stringent conditions to the money's use.[147]

Nevertheless, the federal government would ultimately play a critical role in restoring power to Puerto Rico. Ten days after Maria made landfall, FEMA tasked the U.S. Army Corps of Engineers with "leading the planning, coordination, and integration of the grid restoration" — an unprecedented move for a domestic disaster response, that resulted from a FEMA determination that PREPA was overwhelmed by the scale of the devastation, and lacked the capacity to lead or carry out the restoration on its own. FEMA and the Army Corps would ultimately spend nearly $3.2 billion restoring Puerto Rico's electric system — a mission that concluded in May 2018, with power restored to 98% of customers on the island.[148]

While a number of controversial decisions and political arguments undoubtedly contributed to delaying the progress of the restoration of power following Hurricane Maria, we see that the blackout was ultimately ended by a combined Puerto Rican-federal effort.

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[143] Sullivan, "FEMA Blamed Delays In Puerto Rico On Maria; Agency Records Tell Another Story."
[144] Meyer, "What's Happening With the Relief Effort in Puerto Rico?"
[145] Romo and Florido, "Political Unrest In Puerto Rico After Discovery Of Unused Hurricane Aid."
[146] Willison et al., "Quantifying Inequities in US Federal Response to Hurricane Disaster in Texas and Florida Compared with Puerto Rico."
[147] Fadulu and Walker, "Trump Attaches Severe Restrictions to Puerto Rico's Long-Delayed Disaster Aid."
[148] U.S. Government Accountability Office, "2017 Hurricane Season: Federal Support for Electricity Grid Restoration in the U.S. Virgin Islands and Puerto Rico," 12,14.

### 3.1.3 Resilience efforts since Hurricane Maria

Maria was a pivotal point for Puerto Rico — putting a spotlight on the island's power woes, creating an urgent need for action, and bringing with it the promise of federal aid. In doing so, it also sparked an island-wide debate about the need for resilient decarbonization of Puerto Rico's electric system.

On its part, PREPA has attempted to move forward, submitted a newly revised IRP in mid-2019 that aimed to build a more resilient electric system, based on the lessons learned in the aftermath of Maria.

The 2019 IRP's defining feature is a plan to segment Puerto Rico's electrical system into eight "MiniGrids," each of which would be able to isolate itself from the rest of the transmission system in the event of major transmission failures, and operate independently to serve critical loads for up to a month. PREPA implicitly presents the MiniGrid proposal as a response to the resilience challenge identified by the massive transmission failures that contributed to the post-Maria island wide blackout. As such, the MiniGrids are described as "zones of resiliency into which the system can be segregated during and after a major weather event ensuring that the load can be served using local resources."[149]

The proposal describes each MiniGrid as roughly mapping to one of the seven service regions PREPA currently divides Puerto Rico into, each of which would be given additional generation resources (in the form of solar, storage, and gas turbines). In addition, each MiniGrid region would receive switching/relay/controls upgrades enabling islanded operations, as well significant transmission upgrade within each MiniGrid and between MiniGrids, to support interconnection. Per the modeling conducted by Siemens that PREPA cites, this would hypothetically provide each MiniGrid with the capacity to keep critical loads energized even in the wake of transmission damage of the sort caused by a Category 4 storm like Maria, or another significant disruption of access to energy from one of the large, existing baseload generators.[150]

In order to power these MiniGrids (and meet the new RPS standards), IRP calls for bringing 1800 MW of new utility-scale photovoltaic solar generation online by 2023, in 250 MW increments. If implemented, this would bring total renewable generation to 41% by 2025,

[149] Siemens Power Technologies International and Siemens Industries, "Puerto Rico IRP 2018-2019," 1–02, 1–08.
[150] Siemens Power Technologies International and Siemens Industries, 8–11.

and 68% by 2038 — meeting its 2025 decarbonization target on time, and the 2040 target early. In tandem, it also calls for the addition of 920 MW of battery storage by the end of 2022, with long-term plans calling for 200MW of 2 hour storage capacity, 680W of 4 hour storage capacity, and 400 MW of 6 hour capacity. The IRP mentioned taking combined solar-storage bids, but notes that such a process does not yet exist.[151]

On the transmission and distribution front, the IRP calls for $5.8 billion in spending on transmission infrastructure for its proposed MiniGrid system by 2028 — with $3.87 billion of that spending coming by the end of 2022. MiniGrid spending is broken down into construction of the main backbone lines for the MiniGrids, extensions of those lines, the interconnection of critical loads, and the interconnection of the MiniGrids themselves. It also includes funding for hardening existing transmission infrastructure and replacing aging infrastructure.[152]

Additionally, the IRP contains a separate $911 million in funding for substation resilience (primarily insulation upgrades) and the construction of new standardized 13.2 kV distribution feeder lines, to support the integration of rooftop solar capacity.[153]

This is a substantial departure from PREPA's first IRP, which was approved after extensive modification by the Puerto Rico Energy Commission in September 2016. The 2016 Modified IRP made only passing mention of renewable energy and energy storage, authorizing PREPA to create a bidding process for procuring renewable generation, without noting any specific amounts or types, and requiring that PREPA study the potential for integrating storage into the electric system. It also took a very hands-off approach to investment in the transmission and distribution system that would catastrophically fail just over a year later, authorizing PREPA to "pursue those investments in its transmission and distribution systems that, consistent with prudent utility practice, are required for system stability and operability."[154]

Rather than renewables and resilience, the 2016 Modified IRP was instead focused on PREPA's existing fossil-fueled generation. The primary actions authorized by CEPR were the permitting of a new dual-fuel CCGT unit at Aguirre, along with retrofitting two existing units

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[151] Siemens Power Technologies International and Siemens Industries, 10–02 to 10–03.
[152] Siemens Power Technologies International and Siemens Industries, 10-10 to 10-16.
[153] Siemens Power Technologies International and Siemens Industries, 10–17 to 10–20.
[154] Puerto Rico Energy Commission, "Final Resolution and Order on the First Integrated Resource Plan of the Puerto Rico Electric Power Authority," 87–88.

there to dual-fuel CCGT capability; the permitting of three sub-100 MW dual-fuel CCGT units at Palo Seco, and the planning for an offshore LNG terminal at Aguirre.[155]

However, PREPA's 2019 Revised IRP has met with substantial criticism from watchdogs and environmental organizations, for still placing a huge bet on natural gas infrastructure. In addition to its investments in solar and battery deployment, the IRP also calls for the construction of 1,678 MW of new fossil-fueled generation by 2028, though none are scheduled to come online before 2025.

That includes retrofitting two existing oil-fired plants (San Juan Units 5 & 6), to run on natural gas.[156] Notably, the San Juan retrofit contracts were signed in March 2019, outside of the IRP process but while it was ongoing, and call for an unusual cost structure in which PREPA is paying back the cost via fuel purchase agreements.[157] It also calls for constructing two new 302 MW combined cycle natural gas turbine (CCGT) plants at Palo Seco and Costa Sur, and beginning the preliminary permitting for two more at Yabucoa and Mayagüez, at a cost of $293 million each[158]

It also includes eighteen new 23 MW mobile peaking turbines (a total of 414 MW), which are dual-fuel capable (can run on oil or natural gas), to be distributed geographically across key load regions around the island. PREPA argues the peaker turbines, which would replace 18 older, existing turbines, are "required to provide reliable distributed generation to serve critical and priority loads within the MiniGrids." Each peaker would cost roughly $24 million, for a total cost of $433 million.[159]

In order to support this significant expansion of the electric system's natural gas demands, the IRP proposes the construction of a $472 million LNG natural gas terminal near San Juan, to support the San Juan retrofits and new Palo Seco CCGT, while also proposing preliminary work on two additional LNG terminals at Yabucoa and Mayagüez, to support their expanded generation, at estimated costs of $285 million and $215 million, respectively.[160]

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[155] Puerto Rico Energy Commission, 84–86.
[156] Siemens Power Technologies International and Siemens Industries, "Puerto Rico IRP 2018-2019," 10–03.
[157] Sanzillo and Kunkel, "IEEFA Puerto Rico: Bad Gas Deal Hurts PREPA Chances for a Turnaround."
[158] Siemens Power Technologies International and Siemens Industries, "Puerto Rico IRP 2018-2019," 10–05.
[159] Siemens Power Technologies International and Siemens Industries, 10–06.
[160] Siemens Power Technologies International and Siemens Industries, 10–06 to 10–07.

In a regulatory brief submitted to the Puerto Rico Energy Board in March 2020, the Environmental Defense Fund (EDF) boiled its opposition to PREPA's IRP down to a simple observation: in the wake of the most devastating natural disaster to ever hit Puerto Rico and its power system, PREPA's plan largely appeared to be to stay the course and continue betting on natural gas.

While acknowledging that the moves towards solar, storage, and microgrids were promising from both a resilience and decarbonization perspective the EDF proceeded through a rigorous critique of PREPA's methodology, technical approaches, modeling practices, and even highlighted a conflict of interest —Siemens, the contractor who prepared the natural-gas-heavy IRP, also happens to be the world's third-largest manufacturer of the 302MW F-class natural gas turbines that PREPA proposed purchasing anywhere from two to four of.[161] In the end, the EDF's judgement of PREPA's vision for the next 20 years of electricity in Puerto Rico comes down to: "a failure of imagination."

The EDF argued, not entirely without reason, that PREPA had failed to respond to the challenge at hand with an adequate amount of ambition — and, that even under its 2019 IRP targets, the odds of the utility managing to make its decarbonization targets remained low.

It is beyond our analysis here to consider the full merits of the EDF's critique. However, if nothing else, Puerto Rico certainly appears to have expanded its resilient decarbonization ambitions in the months since the 2019 IRP submission. After the government of Ricardo Rosselló Nevares collapsed in a corruption scandal over Maria aid in August 2019, Secretary of Justice Wanda Vásquez Garced was sworn in as the new Governor of Puerto Rico. Three months later, the government unveiled the final form of the long-planned "Grid Modernization Plan for Puerto Rico" — a ten-year, $21 billion effort to overhaul the island's power systems, with a focus on building in resilience against another Maria-caliber storm. The plan was initially begun under Rosselló's tenure and brought back with new life under Vásquez Garced.

The GridMod plan, as the government calls it, is essentially a modified version of the 2019 IRP with a heavily beefed-up commitment to transmission, distribution, and substation hardening and resilience — $12.2 billion over ten years, nearly double the proposal in the 2019 IRP. It also includes $1.8 billion for advanced metering infrastructure and control

[161] Scott, "GE Wins Most 2018 Gas Turbine Orders; Mitsubishi Wins on New Technology."

systems, as well as a specific $1.76 billion line-item for DERs and localized microgrids to be piloted within the MiniGrids.[162]

Altogether, it appears that while PREPA remains all-in on its natural gas play, the utility (in tandem with the commonwealth's government) have begun to take substantial steps towards building a more resilient, decarbonized electric system. The 2019 IRP represented an important, if imperfect, step in this direction, by placing resilience at the core of the proposed redesign of Puerto Rico's electric system, through the MiniGrid concept, and by making firm commitments to solar generation and energy storage.

While the GridMod plan leaves the natural gas elements of the IRP largely unchanged, it appears to double down on the most promising elements of the IRP — committing to dramatic increases in spending for transmission, distribution, and substation resilience and hardening, as well as breaking out funding for advanced controls, DER, and microgrid technologies that could all help move PREPA towards a more resilient, decarbonized electric system.

Though it remains to be seen if PREPA and the commonwealth can actually execute their extremely ambitious GridMod plan, or even PREPA's relatively ambitious 2019 IRP, the fact that resilient decarbonization has been squarely embedded at the core of Puerto Rico's future electric system planning efforts certainly appears to be a positive trend.

[162] Puerto Rico Central Office of Recovery, Reconstruction, and Resiliency, "Grid Modernization Plan for Puerto Rico," ix–xi.

### 3.1.4 Test of Resilience: 2020 earthquakes

Thus far, we have examined the efforts that PREPA has made to address the challenges facing Puerto Rico's electric system, by centering the concept of resilient decarbonization in its planning efforts. In this final section, we will take a brief glimpse at how those efforts have paid off, by considering how PREPA and Puerto Rico's electric system fared against their first major test of resilience — the 2020 earthquakes.

Beginning at the very end of December 2019, a series of dozens of earthquakes — including 11 measuring above magnitude 5 on the Richter scale — struck off Puerto Rico's southern coast. The largest earthquake, with a magnitude of 6.5, struck on January 7th, and was followed by a magnitude 5.9 aftershock on the 11th.[163]

While there was a great deal of damage to buildings and homes across the Island, the quake on the 7th left the electric system relatively unharmed. As the shaking began, PREPA's generators self-protectively tripped offline, cutting power to the entire island. Minimal damage was reported to transmission or distribution systems, but the 820 MW Costa Sur generating plant, located on the island's southern coast near the earthquake epicenter, was almost completely destroyed. PREPA's CEO, José Ortiz, called the plant "a disaster," noting that it could take up to a year to get it fully operational again.[164]

Remarkably, though, the actual impact on customers was relatively short-lived: by January 13th, less than a week after the strongest quake, PREPA announced that it had restored power to 99% of its customers.[165] While this may seem astonishing in the context of the time it took to get back to 95% or 100% after Maria, it's important to remember that the transmission and distribution systems (key challenges in the wake of Maria) were largely unaffected by these quakes, which mainly impacted generation. Nevertheless, the quakes highlighted the vulnerability of the electric system's centralized, southern-heavy generation fleet.

This was reinforced by a magnitude 5.4 quake that struck the southern coast of Puerto Rico months later, on the morning of May 2, 2020. While the quake knocked the EcoElectrica generation plant offline, causing outages across southern Puerto Rico, PREPA announced

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[163] Chappell and Dwyer, "Puerto Rico Declares State Of Emergency After Quake Rocks Residents Awake."
[164] Gallucci, "Puerto Rico Goes Dark (Again) as Earthquakes Rattle Island - IEEE Spectrum."
[165] Booker, "After Quakes, Puerto Rico's Electricity Is Back On For Most, But Uncertainty Remains."

that it had successfully brought the plant back online and restored nominal service across the island in a matter of hours.[166]

While these incidents were far from a test of Maria-caliber proportions, they nevertheless reveal that while PREPA has made progress in gracefully failing and effectively recovering its system operations, the system itself still has underlying structural vulnerabilities.

[166] Acevedo and The Associated Press, "5.4-Magnitude Earthquake Hits near Puerto Rico."

## 3.2 Northern California (2017-2019)

*When the wind picked up, the fire spread*
*And the grapevines seemed left for dead…*
*And the northern sky looked like the end of days*

– "Grapevine Fires" (2008)[167]

### 3.2.1 2017-2018 CA wildfire seasons

The 2017 wildfire season in California was the most destructive in nearly a decade. From April through December, the state saw 9,270 fires break out. Together, they consumed an estimated 1,548,429 acres of land, damaged or destroyed 10,280 structures, and claimed 47 lives.

Both the death toll and the damage exceeded that caused by the preceding nine fire seasons years combined, with 2017 becoming the most destructive season on record at the time. In fact, five fires that broke out in 2017 remain among the top twenty most destructive fires on record in the state.[168,169]

The fires were spread out across the state for the majority of the year, but a burst of strong Santa Ana winds in December set off a cluster of wildfires in Southern California (including the 280,000 acre Thomas fire, the largest on record at the time) that forced the evacuation of more than 280,000 people. Altogether, the 2017 fires caused an estimated $18.7 billion in damages.[170]

Following on the heels of the destruction of 2017, 2018 saw the worst wildfire season in California history, by nearly every measure. From February through November, the 7,639 fires burning across the state consumed 1,963,101 acres of land, destroyed or damaged 24,226

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[167] Death Cab for Cutie, *Grapevine Fires*.
[168] California Department of Forestry and Fire Protection, "2017 Fire Season."
[169] California Department of Forestry and Fire Protection, "Top 20 Most Destructive California Wildfires."
[170] National Centers for Environmental Information, "U.S. Billion-Dollar Weather & Climate Disasters: 1980-2020," 3.

structures, and claimed 100 lives. Altogether, the 2018 fires caused an estimated $24.5 billion in damages.[171]

This made the 2018 wildfire season the largest, most damaging, and deadliest that California has seen in nearly a century of detailed recordkeeping.

The Mendocino Complex Fire, formed by the merging of two fires that burned across four Northern California counties, became the largest ever recorded in the state. From its ignition in late July, to its containment on November 7th, it burned a stunning 459,123 acres.[172][173]

The containment of the Mendocino Complex fire was seen by many as the end of what was already at that point "California's worst wildfire season ever." However, the very next day, a 96-year-old hook on a transmission line in the Sierra Nevada foothills failed — sparking what would come to be known as the Camp Fire.

By the time it was contained two weeks later, the Camp Fire would become the world's most expensive disaster of 2018, and the deadliest wildfire in California's history.

In the months and years that followed, the aftermath of the Camp Fire would send the largest investor-owned electric utility in the country into bankruptcy, and prompt a frantic scramble to build resilience against the wildfire risks that California's aging power system posed in an increasingly hostile climate.

***The Camp Fire***

> "This is an important safety alert from Pacific Gas & Electric Company: extreme weather conditions and high fire danger are forecasted in Butte County, starting Thursday, November 8, 2018."

Weather: hot and windy; another red flag warning from the NWS; and a wildfire alert from PG&E to keep it company. As many residents have recalled in the years since, it seemed like just another day in Paradise. [174,175]

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[171] National Centers for Environmental Information, 2.
[172] California Department of Forestry and Fire Protection, "2018 Fire Season."
[173] California Department of Forestry and Fire Protection, "Top 20 Largest California Wildfires."
[174] McMullen, "Fire in Paradise."
[175] Canepari and Cooper, *Fire in Paradise*.

Wildfires were no strangers in this heavily forested part of Northern California, especially during the dry autumns of California's longest-running drought. So, it's no surprise that emergency dispatchers in the small town of Paradise were nonplussed by the early reports of a fire that had started out past the smaller towns of Concow and Pulga to their northeast. One dispatcher recalled that at first, what she dubbed "the Camp Fire" due to its proximity to a narrow dirt track called Camp Creek Road, "just seemed like a normal fire."

However, in what would come to be the defining characteristic of the Camp Fire, events escalated alarmingly quickly. The initial report of a fire was called in at 6:33 a.m. PST. In a radio call around 6:44 am, a CAL FIRE officer noted that the winds were too high for aerial suppression, and remarked, "This has got potential for a major incident." As firefighters estimated its size at 200-300 acres, the fire was spreading towards Concow, a town of 700 people halfway between the ignition point and Paradise.

John Messina, the Assistant Chief for CAL FIRE's Butte County Division who took charge as incident commander for the Camp Fire, recalls that by 7:30 am, the fire had picked up and begun to spread in earnest, with a massive column of smoke visible for miles. Within ten minutes, the emergency services dispatch center began getting reports of spot fires breaking out on the eastern side of Paradise, and spreading into the center of town.

Residents, emergency dispatchers, and CAL FIRE officers alike all admitted that they were caught off guard by the sheer speed with which the fire spread, and that the initial response in Paradise was one of confusion, especially about evacuation.

Recordings of 911 calls from that morning reveal emergency service dispatchers rapidly cycling through frantic caller after frantic caller, juggling radio traffic and dispatching firefighters, all while encouraging increasingly concerned residents to evacuate as homes across eastern Paradise began to go up in flames — even if they hadn't been formally told to do so. One caller can be heard asking where the fire is in Concow. The dispatcher hurriedly responds: "Everywhere, it's already in Paradise, we have a major fire — I gotta go," before hanging up.

Eighteen minutes after the fire entered the town, the dispatch center received a call from Cal Fire/Butte County Fire, informing them that they'd just issued an immediate mandatory evacuation order for the entirety of Paradise.

What ensued has played out on screens across the country endlessly in the days since the Camp Fire. Cellphone footage shows residents lined up in bumper-to-bumper traffic, with a billowing plume of smoke overhead. Day rapidly turned to night as the thick black smoke choked out the sun, replacing it with the menacing orange glow of burning homes as residents crept along ember-strewn roads with what one CAL FIRE officer described as “80-100 foot flames” raging on either side.

The driver of the rapid spread was the fire itself. As it grew, the temperature gradient it generated stoked the already-strong winds. Rapid gusts of wind lofted burning embers high into the sky, depositing them miles away.

As a result, the more than 350 firefighters who converged on Paradise had no clear fire front to fight — new fires kept popping up all around them, ignited by lofted embers, and adding to the growing conflagration. Messina says that by 9:23 am, he had conceded that they couldn’t fight or contain the fire — they could merely do their best to rescue people from the flames and enable the evacuation of Paradise. Firefighters drove bulldozers through the flames to move cars blocking evacuation routes, while patrol officers dodged flying embers to rescue elderly residents from their homes — all in a last-ditch effort to escape from the flames.

But by around noon, the damage had been done — Paradise, California had been burned to the ground.

The Camp Fire would continue to slash its way across Northern California, burning 153,336 acres, destroying 18,804 structures, and casing $16.5 billion in damage, before it was finally brought under control and contained on November 25, 2018. In Paradise, what one CAL FIRE officer described as “the largest search and rescue effort operation ever conducted in the state of California” revealed what many already feared.

Claiming eighty-five lives in a span of hours on the morning of November 8$^{th}$, the Camp Fire was the deadliest wildfire in the US in over a hundred years, and one of the worst natural disasters of 2018.[176,177]

However, to call the Camp Fire a “natural” disaster feels like a bit of a misnomer, and not just because of climate change. For while the role of climate change in exacerbating the conditions that make wildfires more likely has been well-documented in the literature, the Camp Fire had a far more proximate cause: an electric transmission system that hadn’t been designed to deal with the extreme weather it now faced, and its owner, the Pacific Gas and Electric Company.

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[176] McMullen, “Fire in Paradise.”
[177] Canepari and Cooper, *Fire in Paradise*.

The most devastating tragedies often begin with the smallest of failures. In this case it was “a 3-inch hook purchased for 56 cents around the end of World War I,” manufactured by the Ohio Brass Company around 1918.[178] Initially a parts supplier for horse-drawn carriages, the firm also made parts for some of the first electric transmission lines in the United States.

The hook in question, known as a C-hook, was attached at one end to transmission tower 27/222, which was constructed in 1921 in a sparsely populated region outside what would later become the small town of Pulga, California. Tower 27/222 was just one of several on the Caribou-Palermo transmission line, constructed in 1921 to carry hydroelectric power by the Great Western Power Company — today, Pacific Gas and Electric (PG&E), the main utility serving northern California. The 56-mile transmission line is one of the oldest in the nation, part of a system of hydroelectric powerhouses and transmission lines stretching into the Sierra Nevada foothills, known as the “Stairway of Power.”[179]

The other end of the C-hook was attached to a series of bell-shaped ceramic insulators connected in series — which were, in turn, connected to a 115 kV electric transmission line.

In the 96 years between 1921 and November 8, 2018, that C-hook was under a great deal of stress. Between the movements of Tower 27/222 and the gyrations of the Caribou-Palermo line in the high winds of the Feather River Valley, the constant motion wore through the hook’s WWI-era galvanized iron — about 70-80% of the way through.[180]

Early on the morning of November 8th, that C-hook gave way, sending the transmission line swinging away from its fixed position on the tower, and causing an arc of electricity that ignited some dry vegetation. At 6:33 a.m. PST, a PG&E worker called in a sighting of smoke outside Pulga. Twenty-four hours later, 85 people were dead and the town of Paradise, California no longer existed.[181]

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[178] Gold and Blunt, “This Old Metal Hook Could Determine Whether PG&E Committed a Crime.”
[179] Blunt and Gold, “PG&E Delayed Safety Work on Power Line That Is Prime Suspect in California Wildfire.”
[180] California Public Utilities Commission, “Incident Investigation Report for 2018 Camp Fire,” CAMP-0011, CAMP-0020.
[181] Gold and Blunt, “This Old Metal Hook Could Determine Whether PG&E Committed a Crime.”

### 3.2.2 Underlying drivers of the wildfires

We will examine three key drivers of the Northern California wildfires: the role of climate change in increasing wildfire risk, the role PG&E played in starting wildfires, and the impact of actions (or lack thereof) on the part of state regulators and policymakers.

***Climate change and wildfire in Northern California***

The past decade has seen a dramatic increase in the quantity and severity of wildfires across the United States — an increase that has been strongly attributed to trends driven by anthropogenic climate change. Per an analysis cited in the NCA, climate impacts were responsible for more than doubling the area burned by wildfires in the U.S. from 1984 to 2015, which reached 25 million acres, as shown in Figure 12.[182]

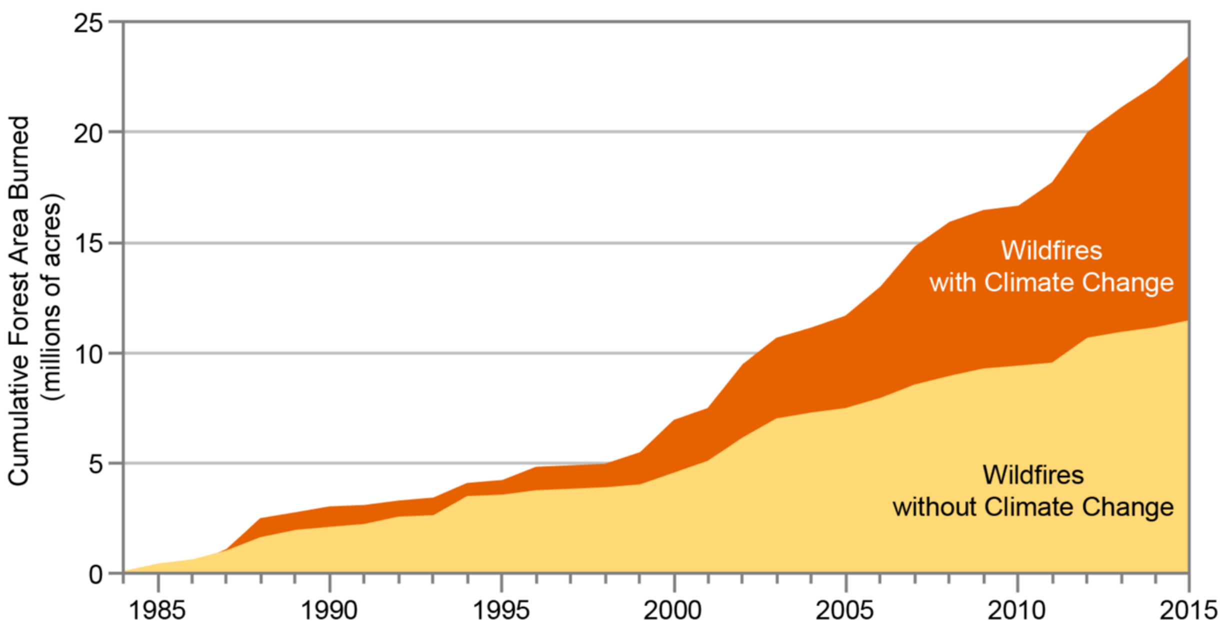


Figure 12. Total area burned by wildfires in the U.S. from 1984-2015, attributed to climate impacts.[183]

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[182] Abatzoglou and Williams, "Impact of Anthropogenic Climate Change on Wildfire across Western US Forests."

[183] U.S. Global Change Research Program et al., "Impacts, Risks, and Adaptation in the United States," 1105.

This increase has been particularly pronounced in California, which saw a fivefold increase in annual burned area from 1972 to 2019. A report from the Wildfire Strike Force, established by newly-elected Governor Gavin Newsom in the wake of the 2018 fire season, noted that the past decade has seen 15 of the 20 most destructive fires in California history — ten of which have occurred since 2015.[184]

Climatic factors have historically been the primary drivers of wildfire in California. A 2009 study found that from 1916 to 2003, the area burned in the western U.S. was more closely related to climatic drivers than other factors such as fire suppression and local fire management.[185,186]

California spent almost the entirety of the 2010s in a state of drought. It was in a formal period of drought from December 27, 2011 through March 5th, 2019 — a total of 376 weeks, or just over 7 years.[187] The worst drought California has faced in more than a century, it dramatically increased wildfire risks across the state.

Also contributing to the increase in available wildfire fuel is a doubling in tree death in mid-elevation conifer forests, like those found in Northern California, which have been partially attributed to climate impacts.[188]

While a wide range of climatic trends have contributed to the increase in wildfire activity, Williams, et al. (2019) find that increased atmospheric aridity caused by warming temperatures was the main contributor to the surge in wildfire activity.[189] They identify a 1.4ºC increase in average warm-season temperature as the key culprit, finding that it led to an increase in the atmospheric vapor pressure deficit (VPD), a measure of the "dryness" of the atmosphere — in line with projections of the impacts of anthropogenic climate change. A drier atmosphere and increased temperatures lead to the drying out of forested areas (wildfire "fuel"), increasing wildfire risks. Based on this, the authors identify an exponential relationship between increases in VPD and the annual area burned by wildfires.

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[184] Governor's Strike Force, "Wildfires and Climate Change: California's Energy Future."
[185] Littell et al., "Climate and Wildfire Area Burned in Western U.S. Ecoprovinces, 1916–2003."
[186] U.S. Global Change Research Program et al., "Impacts, Risks, and Adaptation in the United States," 1115.
[187] National Drought Resilience Partnership, "Drought in California."
[188] U.S. Global Change Research Program et al., "Impacts, Risks, and Adaptation in the United States," 1115.
[189] Williams et al., "Observed Impacts of Anthropogenic Climate Change on Wildfire in California."

Williams, et al. found that across California, "nearly all of the increase in summer forest-fire area during 1972–2018 was driven by increased VPD." Additionally, they noted that stronger winds, later starts to winter precipitation, and declines in fall precipitation, are the primary drivers of fall wildfire events, noting that "warming-driven fuel drying is the clearest link between anthropogenic climate change and increased California wildfire activity to date."

These increasing trends are expected to continue. The NCA estimates that under higher carbon-emissions scenarios, fire frequency across the southwestern U.S. could increase by 25% over the coming decades, while the frequency of very large fires (those larger than 12,300 acres in size) could triple. In addition to causing profound localized devastation, these increases also further elevate the full spectrum of climate risks, as they have caused California's forests to become net emitters of carbon.[190]

While the aggregate statistics are concerning enough, forthcoming work by Goss, et al. (2020) emphasizes the particular risks posed to California by climate-driven increases in autumn wildfires like the Camp Fire. They show that a statewide increase of about 1ºC in average autumn temperature over the past four decades, combined with a nearly 30% decrease in fall precipitation, has more than doubled the number of days falling at or above the 95th percentile risk level for fire weather conditions, since the 1980s.[191]

It's important to note that our understanding of the climatic drivers behind California's wildfires continues to expand. The increase in dry, seasonal coastal winds across Northern California has recently been the subject of significant study, as a potential driver of the recent surge in fires While the Santa Ana winds in Southern California have long been recognized as a major contributor to wildfire risks, the relationship between their Northern Californian counterparts, known as the Diablo winds, and wildfires is still a matter of study. Recent research has found that the frequency of extreme Diablo wind events during the fall in Northern California over the last 20 years (1999-2018) was nearly double that of the preceding 20 years, suggesting a potential connection between the Diablo winds and the recent surge in Northern California fires that we examine here.[192] However, the extent to

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[190] U.S. Global Change Research Program et al., "Impacts, Risks, and Adaptation in the United States," 1116.

[191] Goss et al., "Climate Change Is Increasing the Risk of Extreme Autumn Wildfire Conditions across California."

[192] Liu et al., "Diablo Winds in the California Bay Area."

which Diablo winds have acted as drivers of the Northern California fires remains a matter of ongoing study.[193]

The sizable (and growing) body of climate science and attribution research on the California wildfires makes clear that changing climatic trends — particularly the increase in average temperatures and decrease in precipitation — have been the main drivers of the dramatic increase in wildfire risk over the past several decades. However, even with abundant sources of climate-dried fuel available, wildfires still require a spark.

And over the last several years, that spark has increasingly been provided by the Pacific Gas and Electric Company.

### *PG&E's troubled history*

In the exhaustive wave of investigations that followed the Camp Fire, the California Department of Forestry and Fire Protection (CAL FIRE) and the California Public Utilities Commission (CPUC) found that the Camp Fire was a direct result of PG&E's failure to properly maintain the 96 year old Tower 27/222, and to identify the weakened C-hook before it failed.[194]

In the year and a half since the Camp Fire devastated Paradise, PG&E's role in starting the fire has been firmly established. At the same time, it has become clear that the Camp Fire was far from an aberration.

Over the course of 2018, investigators with CAL FIRE determined that PG&E transmission and distribution lines were responsible for causing 17 major fires during the 2017 wildfire season.[195,196] And in June 2019, they formally confirmed what we learned above — PG&E's equipment was responsible for starting the Camp Fire, as well. The investigators' overwhelming judgement was that the utility had been negligent in dealing with the wildfire risks posed by its power system.

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[193] Goss, Swain, and Diffenbaugh, "Observed Changes in Measures Associated with Wildfire Risk in California."

[194] California Department of Forestry and Fire Protection, "CAL FIRE Investigators Determine Cause of the Camp Fire."

[195] California Department of Forestry and Fire Protection, "CAL FIRE Investigators Determine Causes of 12 Wildfires in Mendocino, Humboldt, Butte, Sonoma, Lake, and Napa Counties."

[196] California Department of Forestry and Fire Protection, "CAL FIRE Investigators Determine the Cause of the Cascade Fire."

However, PG&E's troubles with wildfire go far beyond those 18 major fires in 2017 and 2018. We examined regulatory disclosures that PG&E was required to make to CAL FIRE, which indicate that the utility's equipment was responsible for starting 1,986 fires across the state from June 2014 (when the reporting requirement began) through the end of 2018.[197] This indicates that the 18 major fires that have come to define PG&E's association with the 2017 and 2018 wildfire seasons were merely the tip of the iceberg — nearly two thousand wildfire disasters that thankfully failed to materialize.

PG&E is the largest investor-owned utility in the United States, covering a 70,000 square mile service area — larger than the entire state of Florida.[198] It has 106,681 circuit miles[199] of electric distribution lines and 18,466 circuit miles of interconnected transmission lines, and serves around 16 million people through 5.4 million customer accounts.[200] And yet, while it began the decade as a national leader in electric system decarbonization, PG&E ended it by pleading guilty to 84 counts of manslaughter while in bankruptcy proceedings.

How did this happen? Based on our review of investigative reports from CAL FIRE's investigative materials, publicly-released court documents and regulatory proceedings, and a dogged investigation by the *Wall Street Journal*,[201] we are able to piece together a nearly two-decade-long series of events that laid the groundwork for the disastrous fires of 2017 and 2018, including the Camp Fire.

We find that as the 2010s came to a close, PG&E was being pulled in too many directions, facing a whole new slate of challenges without the institutional capability to meet them. The utility was struggling to deal with a history of accidents and the maintenance of a sprawling power system with components that dated back to 1908, while simultaneously racing to meet California's nation-leading standards for electric system decarbonization. At the same time, it was dealing with financial pressures and continuing a long legacy of shoddy maintenance procedures.

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[197] Pacific Gas and Electric Company, "PG&E Fire Incident Data, 2014-2018."
[198] Pacific Gas and Electric Company, "Service Territory Map."
[199] In electric power, "circuit miles" are equal to the distance travelled by a given transmission or distribution route multiplied by the number of independent electrical circuits present on that route (generally one or two).
[200] Pacific Gas and Electric Company, "Company Profile."
[201] On May 4, 2020, the staff of the *Wall Street Journal* were named finalists for the Pulitzer Prize in National Reporting for the series that this section draws heavily from, which was cited for "showing how a California utility's neglect of its equipment caused countless wildfires, including one that wiped out the town of Paradise and killed 85 people."

This not imply that decarbonization efforts were a driver of the fires — as we learned, the Caribou-Palermo line had been carrying emission-free electricity from the Caribou hydroelectric powerhouse since 1921, decades before the phrase "climate change" even entered the American lexicon.

But to paraphrase the *Wall Street Journal*'s Pulitzer-finalist investigation into the events that led to the Camp Fire: PG&E appears to have been so busy worrying about the past and planning for the future, that the risks of the present snuck up on it.

Depending on which source you consult, PG&E's present woes are rooted either in the aftermath of the 2000-2001 California electricity crisis, which sent it into bankruptcy proceedings until 2003,[202] or in the financial and legal liabilities it faced after the 2010 explosion of a natural gas line in San Bruno, CA that killed 8 people.[203] Regardless of which starting point we choose, though, the underlying story appears to be the same — best expressed by a member of the Independent Review Panel assembled by CPUC to examine the San Bruno explosion.

In January 2019, she told the WSJ that to understand how PG&E so grossly failed to combat the growing wildfire risks it faced, you have to understand its long-term strategy for doing so — or rather, its lack thereof. For most of the past two decades, she said, PG&E has simply been "lurch[ing] from crisis to crisis."[204] As we will see, during that time period, PG&E's institutional capacity for long-term planning was solely lacking — suggesting that the utility failed to grasp the severity of the threat posed by wildfire risk, and lacked the ability to make the long-term, systemic changes needed to build resilience in the face of it.

PG&E's first bankruptcy was a casualty of the early 2000s California electricity crisis, which was sparked in no small part by a 1996 California electric law that deregulated wholesale power prices and forced then unbundling of generation.[205] Peter Darbee, who was brought on as CEO after PG&E exited bankruptcy in 2004, pushed for aggressive earnings growth targets and sought to reshape what he perceived to be stagnant leadership in the company's higher echelons. During his six years at the helm, he ousted more than 40 senior officers, with more than 100% turnover in his executive team. He also began a "Business

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[202] Gold, Blunt, and Smith, "PG&E Sparked at Least 1,500 California Fires. Now the Utility Faces Collapse."
[203] Sweet, "PG&E Fined $3 Million, Ending San Bruno Explosion Case."
[204] Gold, Blunt, and Smith, "PG&E Sparked at Least 1,500 California Fires. Now the Utility Faces Collapse."
[205] Joskow, "California's Electricity Crisis."

Transformation" project, led by consulting firm Accenture, which resulted in the outsourcing of many routine safety and inspection operations to contractors. The project also led to the purchase of new equipment management software systems that were lambasted by field workers for their complexity.

At the same time, PG&E was in the process of becoming a clean energy leader — really, whether it wanted to or not. Throughout the early and mid 2000s, CPUC regulators, along with California lawmakers, encouraged PG&E to pursue more and more emission-free generation sources, and by 2009, PG&E had signed enough contracts for new solar installations to more than double the existing amount of solar in the US.

However, even combination of a corporate transformation and a clean energy push couldn't help the publicly-traded utility's bottom line: PG&E reported declining earnings in 2007, and pulled the plug on Business Transformation by 2009 — after paying over $270 million to Accenture. Per WSJ reports, Accenture consultants laid the blame at the utility's feet — arguing that  that PG&E's management turnover and unwillingness to cut jobs hampered the process.

However, regardless of the where the blame actually lay, the whole effort did nothing to address the un-sexy, yet fundamental problems that would repeatedly haunt PG&E over the next decade: poor (often analog) record-keeping, insufficient maintenance, and aging equipment.

These weaknesses became abundantly clear on the evening of September 9, 2010, when a PG&E-owned natural gas pipeline under San Bruno, CA ruptured suddenly, causing a massive explosion that sent a 3,000-pound piece of pipe flying. The explosion killed eight people and injured dozens, in addition to destroying 37 home and seriously damaging 18 more.[206]

The National Transportation Safety Board (NTSB), which oversees pipeline safety, determined that the cause was shoddy welding when the pipe was first laid in 1956 combined with a pressure spike from poorly scheduled maintenance work. The NTSB faulted PG&E for failing detecting the problem and maintaining its pipelines properly — as well as CPUC for inadequate oversight.[207]

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[206] CPUC Independent Review Panel, "Report of the Independent Review Panel: San Bruno Explosion," 30.

[207] National Transporation Safety Board, "Pacific Gas and Electric Company Natural Gas Transmission Pipeline Rupture and Fire -  San Bruno, California - September 9, 2010," xi–xii.

In April 2015, CPUC imposed a $1.6 billion fine on PG&E, for 2,452 violations of safety rules, and forced it to return $635 million worth of pipeline improvements it failed to properly carry out.[208] A year later, PG&E was convicted on six federal charges, and placed on a five-year federal probation.

In the wake of the San Bruno explosion, the historically poor record-keeping and maintenance systems of PG&E's natural gas operations came under close scrutiny — as they would for its electric system, less than a decade later. Faced with an order from CPUC to conduct a full audit of its records, PG&E was forced to commandeer a San Francisco arena and physically spread out pallets of records dating back decades, in an effort to ascertain its actual safety and maintenance situation.[209] Facing continued backlash, the utility also accepted the resignation of a number of senior executives, including CEO Peter Darbee,[210] and brought Geisha Williams — a seasoned utility executive who has previously been at Florida Power & Light — in as a fresh face to oversee its electric power division.

Chastened by the experience of San Bruno, Darbee's successor Tony Earley put a focus on speeding up gas and electric system improvements, and committed to using the utility's profits to pay for a significant portion (as opposed to passing the cost on to ratepayers). Historically, PG&E's maintenance spending had followed a 5:1 ration of electric to gas, but that began to reverse under Earley. By 2016, the utility was spending $658.3 million on gas system maintenance and around $598 million on electric system maintenance — in additions to multibillion-dollar investments in upgrading and replacing infrastructure.

Under Earley, both the British risk managers Lloyd's and a former NTSB chair were both brought in to consult on safety of the gas operations, with both focusing in on poor record keeping and management in PG&E's maintenance procedures. Notably, while both pointed out that the same vulnerabilities existed in the utility's electric system and offered to examine it as well, both were rebuffed.

At the time, PG&E used reliability data, which showed decreasing annual outages, as the primary gauge of its electric system's health. However, these data were significantly influenced by the adoption of automatic recloser technology, which served to shorten power outage times by reenergizing lines after brief outages. However, as PG&E would later

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[208] Smith and Sweet, "California Fines PG&E $1.6 Billion for Deadly Gas Explosion."
[209] Fagan, "PG&E Launches Huge Paper Chase for Pipeline Data."
[210] Leaving PG&E in the wake of San Bruno, Darbee received a $34.8 million retirement package.

discover, this automatic reenergizing often served to spark wildfires. Additionally, the focus on reducing systemwide outage times and frequency — and their disruption to customers — may have skewed PG&E's efforts towards focusing on urban/suburban infrastructure, over the rural lines like Caribou-Palermo which, while serving dramatically fewer customers, face much greater fire risk.

Earley stepped down as CEO at the end of 2016, and Geisha Williams succeeded him in March 2017. Her early tenure was marked by a focus on reducing costs and increasing affordability, and she notably cut 1,200 employees and contractors from the utility's workforce.

Then the 2017 wildfires, which raced across Northern California's wine country — seventeen of which would ultimately be blamed on PG&E's equipment. The WSJ recounts that Williams was deeply shaken by her visits burned out communities, in the aftermath of the fires. Speaking to investors shortly after, she admitted: "I've seen firsthand the destruction that hurricane force winds can bring to a community, but this was like nothing I've ever seen."

What caused the fires to take such a devastating toll? We've already examined the numerous climate trends that have driven the increase in extreme wildfire risk in Northern California over the past several decades. However, it appears that PG&E was insufficiently prepared to address those risks.

There was a longstanding perception within California's electric community that PG&E, with its operations across Northern California, faced significantly less wildfire risk than the two major Southern California utilities. San Diego Gas and Electric (SDG&E) and Southern California Edison (SCE) are both subject to the region's dry Santa Ana winds, which are (in)famous for stoking wildfires. In the previous section, we examined recent research suggesting that the number of extreme Diablo wind events — counterparts to the Santa Ana — in Northern California from 1999-2018 was double that of the previous two decades: suggesting that Northern California wildfire risks were becoming more and more similar to those faced in Southern California.

While the extent of the Diablo winds' influence is still under study, our examination of the full range of climatic trends leaves no doubt that wildfire risk was increasing across the state, and particularly in Northern California, during. the 2000s and 2010s. Coupled with increased population growth in densely forested areas on the edges of the state's sprawling metropolises (commonly known as the wildland-urban interface), and a once-in-a-generation drought that began in 2011, these trends were a clear warning sign for utilities.

SCE and SDG&E began taking steps to combat the growing risk in the 2000s. They began installing weather stations, developing plans to preemptively shut off power in areas of elevated wildfire risk, replacing over 16,000 wooden poles with steel ones, insulating and spacing out power lines, and ensuring that their equipment could handle up to 85 mph winds. While all those efforts remain ongoing, PG&E didn't begin adopting these measures until the 2010s, for the most part — and has only begin to plan for some of them in the last three years. Per one report, the utility was apparently caught off guard by the speed with which the drought attacked "heavily wooded areas north of San Francisco and outside Sacramento."[211]

While PG&E was slowly coming to terms with its increased wildfire risk, it was also muddling its way through a massive maintenance backlog for its aging electric system.

There's no other way to put it: PG&E's transmission system was (and remains) incredibly old. Tower 27/222, whose failure sparked the Camp Fire, was constructed in 1921. However, data on the age of PG&E's transmission system, shown in Figure 13, reveals that a significant portion was much older. We obtained this data from a confidential study that utility consulting firm Quanta Technology conducted for PG&E in 2010, which was released as part of federal court proceedings.[212]

The Quanta data reveals that 27.7% of PG&E's 115 kV transmission lines were installed before Tower 27/222, with the oldest dating back to before 1908. An internal PG&E presentation from 2017, also released as part of the court documents, reveals that based on the Quanta analysis, the utility estimated that the mean life expectancy of its transmission towers was 65 years, while the average age of the towers was 68 years. Additionally, it noted that towers in valley regions — like the Caribou-Palermo line — had a maximum life expectancy roughly defined as "100+" years.[213]

Looking back at the Quanta data, we can conservatively state that by 2017, 62.9% of PG&E's 115 kV towers and 60.2% of its 230 kV towers were already beyond their mean life expectancy. Moreover, Tower 27/222 and the 27.7% percent of PG&E's 115 kV towers that

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211 Gold, Blunt, and Smith, "PG&E Sparked at Least 1,500 California Fires. Now the Utility Faces Collapse."

212 Pacific Gas and Electric Company, "Pacific Gas and Electric Company's Response to Request for Information," Doc. 1078-6, 27 of 57.

213 Pacific Gas and Electric Company, 1078–5, 8 of 18.

were around 100 years old at the time were bumping up against what the utility deemed their maximum life expectancy.

Thus, based on PG&E's own internal data and analysis, we find that by the time of the wine country fires of 2017, three-fifths of the utility's transmission towers had exceeded their anticipated mean life expectancy, and 27.7% had hit or *exceeded* what PG&E believed would be their maximum lifespan.

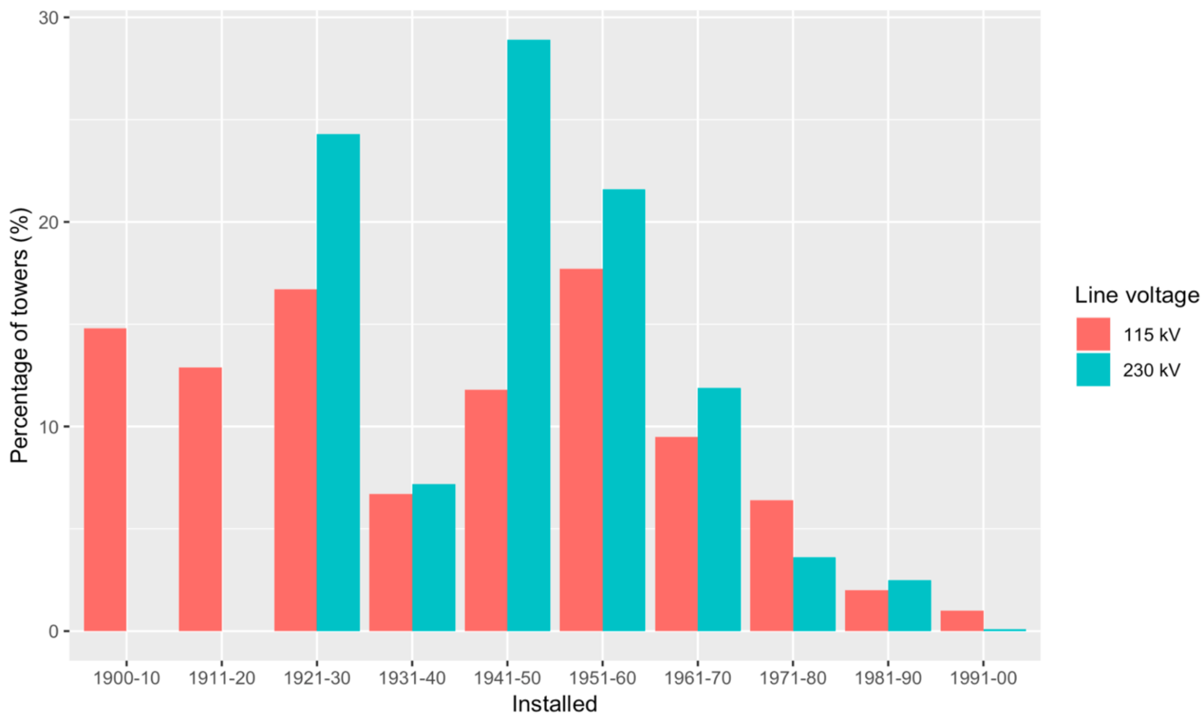


Figure 13. Age distribution of PG&E transmission towers[214]

The risks posed by PG&E's aged-out electric system infrastructure is apparent from the utility's struggles over the past decade, as it sought to deal with the dual challenges of increasing wildfire risk from fuel drying, and equipment failure.

From 2013 to 2017, PG&E had over 16,000 sections of high voltage lines fail due to contact with vegetation or equipment failure — that's one every three hours. Thirty percent of those failed lines remained energized, posing a severe risk of fire.[215]

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[214] Pacific Gas and Electric Company, Doc. 1078-6, 27 of 57.

[215] Gold, Blunt, and Smith, "PG&E Sparked at Least 1,500 California Fires. Now the Utility Faces Collapse."

By the beginning of 2018, PG&E estimated that there were 120 million trees that posed a risk of coming into contact with its power lines, and made plans to trim 1.4 million per year.[216] However, dealing with the vegetation problem became its own thicket, as the utility was forced to allow its contractors to lower hiring standards in the face of a shortage of qualified workers. At the same time, many of the trees it had to deal with were on private land, forcing negotiations with landowners and residents.[217] In a perverse twist, The Butte Fire in September 2016 was caused by a tree that became exposed to the wind, following the removal of two trees by PG&E crews, that then was blown onto a 12 kV line, sending embers onto dry grass.[218]

This brings us back to the Caribou-Palermo line. Over the preceding two decades, the line had been strained by the expansion of the woodland towns of Paradise and Chico that it served, as demand increased in the densely forested, wildfire-prone area. In 2010, the California Independent System Operator (CAISO), which oversees California's transmission system, noted in its annual transmission plan that more and more sections of the line were becoming thermally overloaded by the increased demand for power flowing through it. However, CAISO concluded that this didn't yet require an immediate response, leaving "more than ample time to schedule implementation by 2018" of an eventual solution.[219] As we now know, that solution was never implemented.

PG&E's faced a range of maintenance woes as a result of Caribou-Palermo's aging transmission infrastructure. In December 2012, a storm blew down 5 towers on the line. PG&E replaced them with temporary wooden towers and came up with a $2.9 million replacement plan. In January 2017, wind pushed trees into the line, leading to a fault that shutdown a power house — which took 6 days to restore.[220] These were likely compounded by PG&E's poor record-keeping and maintenance management systems, with reports indicating that as late as 2015, it was still relying on "paper wall maps and push pins" to track maintenance operations in some of its control centers.[221]

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[216] Gold, Blunt, and Smith.
[217] Gold, Blunt, and Smith.
[218] Gold, Blunt, and Smith.
[219] California Independent System Operator, "Final California ISO Transmission Plan, 2010," 79.
[220] Blunt and Gold, "PG&E Delayed Safety Work on Power Line That Is Prime Suspect in California Wildfire."
[221] Blunt and Gold.

In order to deal with Caribou-Palermo's deteriorating conditions, PG&E had repeatedly proposed a $30.3 million maintenance and equipment repair project on for the line, set to begin in 2013. However, the project was subsequently pushed to 2014, 2015, and 2016, before finally being rescheduled for June 2018.

The plan noted that one in four wire spans were too close to vegetation, and proposed "swapping 61 lattice towers with more modern tubular-steel poles." At the time of the Camp Fire, PG&E hadn't yet begun the maintenance, the costs of which would've been passed along to ratepayers.[222] The utility attributed the delays to engineering and permitting challenges, including challenges related to the fact that the line crosses through a national forest.

However, while the delay is emblematic of PG&E's overall challenges with wildfire risk management and infrastructure maintenance, that point may have been moot with regard to the Camp Fire — in the aftermath of the Camp Fire, PG&E admitted that Tower 27/222 was not among those scheduled to be inspected as part of its long-delayed maintenance project.[223]

Following the Camp Fire in November 2017, PG&E briefly restarted Caribou-Palermo, subjecting it to close inspection including tower climbs in December 2018, before shutting it down indefinitely.

In the aftermath of the Camp Fire, PG&E's spending on its transmission system in 2018 was set for $1.96 billion. However, this spending has been criticized by downstream utilities, state regulators and PG&E's own internal audits for being a "black box," with insufficient prioritization of the most critical projects, due in large part to a lack of records and data, in favor of getting their rate-based money spent.[224] It was approved to spend $97 million on overhauling that system and doing an equipment inventory on it distribution systems between 2014 and 2016, but only spent 15% of the money actually on that.

What have the past two winding tragic, and often frustrating decades of PG&E's history shown us about its role in starting wildfires? That PG&E was responsible for some of the most devastating fires of 2017 and 2018 cannot be denied, but as we discovered, the utility and its equipment sparked almost 2000 others that luckily were nowhere near as devastating.

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[222] Blunt and Gold.
[223] Blunt and Gold.
[224] Blunt and Gold.

As we hinted at the outset, we found that PG&E suffered from disaster-induced priority whiplash. After emerging from its first bankruptcy in 2004, it focused on boosting earnings, slashing costs, and investing in clean energy. But following the San Bruno explosion in 2010, it swung its maintenance spending focus towards its gas system, while letting warnings that its electric system faced similar challenges slide. And while it's swung spending back toward the electric system since 2018, its track record of delays indicates that there's no telling if or how it's promised $1.96 billion might be spent.

Examining previously-confidential internal data on PG&E's century-old electric transmission system, we found that the majority of its transmission towers are past their mean expected lifespans, and that nearly two-thirds have hit or exceeded their maximum life expectancies. But even in the face of these concerning statistics about its severely again infrastructure, the utility repeatedly pushed off maintenance on the century-old transmission line that would spark the Camp Fire — and later admitted that even if carried out, it likely wouldn't have prevented the failure of Tower 27/222. And its maintenance program as a whole was hindered by an antiquated record-keeping and management system, as well as chronic missteps.

All this, while it failed to grasp and respond to the increasingly clear, climate-driven trends that dramatically increased the risk of wildfire in Northern California over the past four decades.

As we've argued from the outset, PG&E does appear to have left the present risk of climate-enhanced wildfires creep up on it, while it was busy dealing with past challenges and planning for future decarbonization.

However, in the face of this chronic pattern of missteps, we are also led to wonder who, exactly, was supposed to be keeping PG&E in line. What role did state regulators and the state government played in shaping the conditions that contributed to the 2017-2018 wildfires?

***Role of CPUC and California government***

Our examination thus far of the impacts of climate change and PG&E's chronic missteps paints a compelling, but incomplete picture of the underlying drivers of the 2017-2018 California wildfires. The missing piece? The role of California state government, particularly the California Public Utilities Commission.

Over the past 23 years, PG&E has paid more than $2.6 billion in state and federal fines and lawsuit settlements, for a pattern of behavior including failures to adequately maintain its gas and electric systems, insufficient candor and actively misleading regulators, contaminating groundwater with carcinogens,[225] failing to meet required targets, prohibited and unethical political activities including improper interactions with CPUC staff, and a litany of safety violations.[226,227]

Yet as we will see, even after a quarter-century of chronic violations by PG&E, CPUC struggled to oversee the nation's largest investor-owned-utility in a timely and effective manner.

At the turn of the 2010s, California's state government was all-in on climate action and electric system decarbonization. Less than eight months after the San Bruno explosion, Governor Jerry Brown signed legislation increasing California's renewable portfolio standard to 33% of electric generation by 2020. At the same time, as we've previously noted, PG&E was continuing to spend billions on renewable energy procurement, to keep abreast of the RPS as customer rates continued to rise.

The California Public Utilities Commission is the largest state public utility regulator in the nation, double the size of the next largest (Virginia's). In addition to electric and natural gas systems, the Commission also oversees a range of industries spanning everything from railroads, to mobile homes, to ridesharing. But in interviews, former CPUC officials have argued that the commission's focus on decarbonization over the past two decades, driven by political leaders in Sacramento, has crowded out the regulator's already-anemic safety efforts.[228]

Two months after Brown signed the RPS increase into law, the Independent Review Panel assembled by CPUC to examine the San Bruno explosion released its assessment of both PG&E and CPUC's performance in the years leading up to the explosion. The Panel noted CPUC's "long-standing reputation for policy innovation" especially when it came to climate change and renewable energy development. However, it noted that as a result of its expansive policy focus, CPUC lacked "unanimity of view regarding how the agency's

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225 After polluting a small town's water supply with carcinogenic hexavalent chromium, PG&E paid $333 million in 1996 to settle *Anderson, et al. v. PG&E* — a class-action lawsuit that would go on to bring a legal clerk named Erin Brockovich to national prominence.

226 Eastwood, "PG&E's Long Record of Run-Ins With Regulators."

227 Eastwood, "PG&E Penalties and Settlements Through the Years."

228 Blunt and Gold, "'Safety Is Not a Glamorous Thing.'"

resources should be allocated, what issues should become the primary agenda of the Commissioners, what skills are needed within the Commission, and what areas provide the best promotional paths for talented individuals."

While consider CPUC's lack of a unified policy focus, the Panel did note one point upon which the Commissioners were, in fact, unanimous: "they do not focus on the Commission's safety mandate – unless there is a problem escalated to them."[229]

This fundamentally reactive approach to safety issues is exemplified by CPUC's response to the onset of an unprecedented drought beginning in 2011.

Much of PG&E's spending and investment on safety and maintenance is overseen by CPUC. Until recently, the Commission's interest in the area was primarily concerned with vegetation management — ensuring that trees wouldn't strike power lines, sparking fires.[230]

However, as trees began dying en-masse across the state in 2011 and 2012 from a combination of drought and invasive bark beetles, CPUC took action. In January 2012, the Commission issued orders requiring the Southern California electric utilities (including SCE and SDG&E) to prepare fire prevention plans, as well as institute annual patrols and 5-year detailed inspections of their electric systems. However, Northern California utilities — including PG&E — were only required to conduct patrols and inspections half as frequently, and the decision on whether or not to produce fire prevention plans was left up to their judgement.[231] (PG&E ended up submitting a plan.)[232]

In explaining their more lenient approach towards PG&E and Northern California utilities, CPUC argued that "there is no history of catastrophic power-line fires in Northern California, and Northern California does not experience Santa Ana windstorms that contribute significantly to the risk of catastrophic power-line fires in Southern California." However, in the same order, the Commission also admitted that "the magnitude of the risk of catastrophic wind-caused power-line fires occurring in Northern California is unknown at this time."[233]

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[229] CPUC Independent Review Panel, "Report of the Independent Review Panel: San Bruno Explosion," 24.
[230] Blunt and Gold, "PG&E Delayed Safety Work on Power Line That Is Prime Suspect in California Wildfire."
[231] Blunt, Gold, and Smith, "PG&E: Wired to Fail."
[232] Pacific Gas and Electric Company, "Fire Prevention Plan."
[233] California Public Utilities Commission, "Decision 12-01-032: Adopting Regulations to Reduce Fire Hazards Associated with Overhead Power Lines and Communication Facilities."

Eight years, and more than 18 catastrophic wind-caused power-line fires later, the benefit of hindsight shows us how PG&E's reactive, historically-driven approach to safety regulation was a crucial turning point. Would PG&E have caught the weakened C-hook on Tower 27/222 if it had been forced to conduct more frequent patrols and inspections? That's a counterfactual we cannot answer. However, it does appear that CPUC suffered the same failure to proactively contend with the growing risks of wildfire in Northern California that bedeviled PG&E.

Even so, the Commission deserves some credit for adapting as the situation worsened. In January 2014, Governor Brown declared a state of emergency over the drought, and CPUC ordered California's electric utilities (this time, including PG&E) to "begin reporting the number of fires started by their equipment." It's only because of this mandate that we were able to calculate that PG&E was responsible for starting 1,986 fires between June 2014 and the end of 2018.[234]

In April of that year, federal criminal charges were filed against PG&E, which would result in its 2016 conviction and placement on a five-year federal probation. CPUC added to the federal action in April 2015, with its $1.6 billion fine and forced ratepayer rebates

CPUC finally began an investigation of PG&E's electric system safety in 2015, but as of December 2019, the investigation remained ongoing. In the meantime, the 2017, 2018, and 2019 wildfire seasons came and went — and PG&E filed for bankruptcy.[235]

Reporting suggests that CPUC has historically struggled to adequately support safety inspections and investigations. While it more than tripled the size of its safety and enforcement division in the wake of the San Bruno explosion, it still has problems hiring and retaining qualified regulatory and engineering staff. The WSJ also found numerous apparent instances of revolving door regulation and hints of regulatory capture, citing numerous instances of apparently inappropriate contact/coordination between PG&E and CPUC staff regarding safety and enforcement matters.[236]

What do we make of CPUC's halting performance? We find that the Commission's policy focus on climate change and clean energy, driven in no small part by escalating RPS targets from Sacramento, played a role in pulling its focus from its safety mission. However,

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[234] Blunt, Gold, and Smith, "PG&E: Wired to Fail."
[235] Blunt and Gold, "'Safety Is Not a Glamorous Thing.'"
[236] Blunt and Gold.

we find that a far more significant driver of its safety missteps was its reactive safety posture, which favored historical data and appears to have missed crucial opportunities to act based on informed projections of growing climate risk. As a result, it — like PG&E — acted too slowly to confront the growing wildfire risk in Northern California.

### 3.2.3 Aftermath: PG&E and the "first climate bankruptcy"

The terrible destruction caused by the 2017 and 2018 wildfires can be quantified in many ways: the 147 lives tragically lost, the 30,500 structures destroyed, the 3.5 million acres burned, the $43.2 billion in damage costs. However, these statistics leave out one of the most prominent casualties of the fires:

The Pacific Gas and Electric Company, itself.

By the end of 2018, PG&E was already facing 700 lawsuits resulting from the 2017 wine country fires. By January 2019, 50 more lawsuits (six seeking class-action status) as a result of the Camp Fire had been added to that pile. Together, PG&E's legal liabilities for the two wildfire seasons were estimated to be more than $30 billion. This rivaled the company's peak market capitalization of $36.7 billion, reached in 2017, and was more than double the $12.3 billion valuation it fell to by the time the Camp Fire was contained at the end of November 2018.[237] As the financial curtain began to descend on the company, Geisha Williams resigned as CEO at the request of PG&E's board on January 13th, after just 14 months on the job.

The next morning, PG&E announce it intended to seek Chapter 11 bankruptcy protection.

While the loss of life and the physical destruction wrought by the Northern California wildfires are staggering, it is important to note that their legal and financial consequences — and the thresholds they crossed — are what appear to have pushed PG&E over the brink. After all, it was not the physical damage caused to its power lines that sent PG&E into bankruptcy, but the legal and financial liabilities it faced for failing to prevent its lines from damaging hundreds of thousands of acres and taking more than 80 lives.

To understand how PG&E ended up in this liability vise, leaving it no choice but to file for bankruptcy, we must first consider the unique manner in which utilities can be held liable for damages they cause, under California's application of a legal doctrine known as "inverse condemnation."

The Fifth Amendment to the U.S. Constitution ends with the phrase "nor shall private property be taken for public use, without just compensation." Known as the "Takings Clause," it places limits on the government's power of eminent domain — it's ability to seize private

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[237] Blunt, Gold, and Smith, "PG&E: Wired to Fail."

property for public purposes — by requiring that the government pay "just compensation" for the property it is taking.

Article I, §19 of the California Constitution contains a similar provision, which mandates that "Private property may be taken or damaged for a public use and only when just compensation, ascertained by a jury unless waived, has first been paid to, or into court for, the owner."[238] It also lists a number of examples of a "public work or improvement," explicitly including utility or energy-related infrastructure.

However, over the past 135 years, California courts have built a framework of legal precedent upon Article I, §19 that extends far beyond just compensation for eminent domain.[239]

In 1885, the California Supreme Court ruled that property owners were owed just compensation under Article I, §19 even if the government didn't directly take their property from them, but merely caused damage to the property or caused the owner to incur losses, as the result of a "public work or improvement."[240] This set a precedent that someone whose property was damaged due to a public work could seek compensation for the damage.

Nearly a century later, the Court built further upon this precedent, with a 1979 ruling that stated that "an investor-owned utility was more like a government entity than a private employer."[241] Based largely off the significant role that CPUC sees in overseeing the operations of utility companies in California, this precedent meant that in many cases, an investor-owned utility like PG&E could be made to bear the same legal responsibilities as the government itself

And in 1999, the Court held that — even in the absence of wrongdoing — an investor-owned electric utility (SCE) was liable, under Article I, §19, for damages to private property that were caused by a wildfire started by its power lines.[242]

Thus, over the course of 114 years, California adopted the legal precedent that an investor-owned utility like PG&E could be held liable for any incidental damages to private property caused by the operation of its electric system — specifically addressing damages

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[238] Article I, §19.
[239] California State Association of Counties, "Inverse Condemnation and Utility Liability."
[240] *Reardon v. San Francisco* (1885) 66 Cal. 492, 501
[241] Gay Law Students Association v. Pacific Telephone & Telegraph Co. (1979) 23 Cal.3d 458, 469
[242] Barham v. Southern California Edison Company (1999) 74 Cal.App 4th 744

caused by power line-sparked wildfires — regardless of whether or not the utility did anything wrong in the process.

CPUC added to this, establishing a rule that in order for a utility like PG&E to pass the costs incurred as a result of Article I, §19 liability on to ratepayers, the actions that resulted caused the damage must have been the result of "just and reasonable" actions on the part of the utility.

Together, this body of judicial precedent and regulation forms California's near-unique interpretation of the legal doctrine of "inverse condemnation." [243] This interpretation means that in a case where a utility was shown to have failed to "reasonably" managed its electric system — say, by inadequately addressing climate-driven wildfire risk — its shareholders would be required to foot the bill for the damages.

Having examined the doctrine of inverse condemnation, it will come as no surprise that it lies at the core of the financial challenges that wildfire risks have forced California's electric utilities to confront.

A month after the wine country fires in 2017, CPUC concluded a decade long regulatory rulemaking by siding firmly with its interpretation of the doctrine of inverse condemnation. The Commission ruled that SDG&E couldn't pass on the $379 million in inverse condemnation costs from the Witch Fire, the second-largest of 2007, to its ratepaying customers, as it had failed to act as a "reasonable and prudent" manager of its equipment — and that passing the costs along would therefore fail to be "just and reasonable.[244,245]

While the direct financial costs of the decision were borne solely by SDG&E, the principle at stake was clearly on the minds of other California utilities. Months before the wine country fires, PG&E had sought to join the proceeding on behalf of SDG&E, citing (among other reasons) the increased, climate-driven wildfire risks that it was rapidly being forced to confront.[246] As early as the end of 2017, PG&E had begun to regard the possibility of a surge in inverse condemnation liabilities resulting from climate-driven wildfire risk as an existential threat.

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[243] Alabama is the only other state with a similarly expansive inverse condemnation interpretation.

[244] California Public Utilities Commission, "Decision Denying Application of San Diego Gas & Electric Company (U902E) for Authorization to Recover Costs Related to the 2007 Southern California Wildfires Recorded in the Wildfire Expense Memorandum Account (WEMA)."

[245] Nikolewski, "CPUC Rules against SDG&E in 2007 Wildfire Case."

[246] Nikolewski, "Why 2 Other California Utilities Have Joined SDG&E's Push to Make Consumers Pay for 2007 Wildfire Costs."

Though California passed legislation shielding PG&E from some of the costs of the 2017 fires, it still left the utility exposed to significant inverse condemnation liabilities — and it didn't cover the 2018 fires.[247]

As a result, the consequences for PG&E in the aftermath of the Camp Fire were swift. Facing an estimated $30 billion in liabilities from the 2017 and 2018 fires, PG&E filed for Chapter 11 bankruptcy in January 2019. From the week before the Camp Fire, to the morning it announced it would seek bankruptcy protection, PG&E's stock lost 84.8% of its value, falling from $47.44 to $7.23 per share — and out of the S&P 500 index.

In the year and a half since it filed for bankruptcy, PG&E has arranged for a multi-billion-dollar settlement with its creditors and pled guilty to 85 counts of negligent manslaughter.

On March 17, 2020, PG&E revealed in a filing with the Securities and Exchange Commission that it had reached a settlement with the Butte County District Attorney's Office to plead guilty to 84 counts[248] of felony involuntary manslaughter and one felony count of unlawfully causing a fire. The utility agreed to pay a fine of roughly $3.5 million (the statutory maximum),[249] as well as around $500,000 to Butte County as reimbursement for the costs of investigation. It will also be subject to two years of probation overseen by a federal monitor, and separately agreed to cover an expected $15 million cost for replacing a canal that supplied much of Butte County's water that was destroyed in the fire.[250]

In exchange, Butte County and the State of California agreed "that no other or additional sentence will be imposed on the Utility in the criminal action in connection with the 2018 Camp fire."[251] The plea agreement requires approval from the Butte County Superior Court and the U.S. Bankruptcy Court for the Northern District of California, but a scheduled April 24th hearing was postponed after the court curtailed activities due to the COVID-19 pandemic.

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[247] Gold, Blunt, and Smith, "PG&E Sparked at Least 1,500 California Fires. Now the Utility Faces Collapse."

[248] The official death toll from the Camp Fire stands at 85, but the grand jury in Butte County found that one death resulted from suicide as the flames approached and thus did not hold PG&E liable.

[249] It is worth noting that under California Penal Code §193, each count of felony involuntary manslaughter is punishable by a maximum of four years in prison — with 84 consecutive counts theoretically punishable by 336 years' imprisonment.

[250] Blunt, "PG&E to Plead Guilty to Involuntary Manslaughter Charges in Deadly California Wildfire"; Penn and Eavis, "PG&E Will Plead Guilty to Involuntary Manslaughter in Camp Fire."

[251] Pacific Gas and Electric Company and PG&E Corporation, "Form 8-K."

Over the course of 2019 and the beginning of 2020, PG&E has made steady progress towards emerging from bankruptcy. In June 2019, it agreed to a $1 billion settlement with local governments and state agencies impacted by the wildfires — including $270 million to the town of Paradise.[252] In September, it reached an $11 billion settlement with insurance companies and hedge funds, to reimburse them for insurance claims they paid out as a result of the fires.[253] And it has reached a $13.5 billion settlement with the roughly 70,000 victims of the fires, which must be approved by two-thirds of them but is generally expected to pass, if narrowly.[254,255] In March 2020, the utility secured Governor Newsom's support of its bankruptcy plan, in exchange for increased oversight by CPUC, a commitment not to pay dividends to shareholders for three years, and a commitment to explore selling the company if it isn't able to gain approval for its plan and exit bankruptcy proceedings by the end of June 2020 — approval which the bankruptcy judge has indicated he is inclined to grant. The sale condition was aimed at placating Newsom, who had previously threatened to explore a state takeover of PG&E, if it failed to present a bankruptcy plan that sufficiently protected wildfire victims and the ratepaying public.[256][257] With interim CEO Bill Johnson, who was brought on to lead the company through bankruptcy, planning to step aside in favor of a new management team once the company makes its exit, it appears that PG&E has gained a new lease on life.

PG&E's bankruptcy serves as a stark reminder that resilience is integral to the success of decarbonization efforts. It also reminds us of the catastrophes, both physical and legal/financial, that can occur if it is neglected.

Gundlach (2020) notes that the PG&E bankruptcy process has placed into jeopardy the $42 billion in power purchase agreements that the utility had made with renewable energy developers, which reach out more than a decade.[258] This is a concrete example of a lack of resilience (which led to the wildfires causing such severe damages) directly affecting decarbonization efforts. This effect is likely to extend beyond merely existing contracts. After all, it seems reasonable to imagine that PG&E might find it difficult to convince regulators,

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[252] Ailworth, "PG&E Reaches $1 Billion Settlement With Paradise, California Governments."
[253] Gold and Brickley, "PG&E Reaches $11 Billion Settlement with Insurers over Deadly Wildfires."
[254] Penn, Hepler, and Eavis, "PG&E Reaches $13.5 Billion Deal With Wildfire Victims."
[255] Penn and Eavis, "PG&E's Settlement With Wildfire Victims Faces Crucial Vote."
[256] Blunt, "PG&E Reaches Deal With California Governor on Bankruptcy Exit."
[257] Scurria, "Bankruptcy Judge Won't Stand in Way of PG&E Settlement Vote."
[258] Gundlach, "Climate Risks Are Becoming Legal Liabilities for the Energy Sector."

lawmakers, and the public to get on board with plans to expand its electrical system, while simultaneously explaining its difficulties in preventing its existing infrastructure from burning down large swathes of the state each year.

Questions also exist as to the role that inverse condemnation, and the state mandate to serve the increased number of Californians moving into high wildfire risk areas, have played in hampering PG&E's decarbonization efforts. In September 2018, after Governor Brown ramped the California RPS up to 60% by 2030, then-PG&E CEO Geisha Williams contended that the utility's ability to finance efforts to meet the state's aggressive decarbonization targets was being actively harmed by the looming threat of inverse condemnation liabilities from wildfires.[259] However, a January 2019 analysis by researchers at Columbia concluded that while California's "strict liability" interpretation of inverse condemnation is "not constructive, the degree to which CPUC's investigation found fault in PG&E's actions means that the utility would likely still have been held liable for a similar amount, even in the absence of inverse condemnation.[260]

The PG&E bankruptcy shows us that climate risk tipping points and critical thresholds aren't just physical — they can be legal and financial, too. PG&E's physical exposure to wildfire risk didn't suddenly increase following the 2017-2018 wildfire seasons, but its legal liability as a result of that risk certainly did. The majority of PG&E's power system is, by all appearances, still perfectly functional and carries a whole lot of value — for the most part, it's a perfectly fine power system. It was legal and financial liabilities that forced PG&E into bankruptcy, not the physical devastation incurred by the fires. In this way, PG&E is not so dissimilar from PREPA. In addition to the physical damage wrought by extreme weather, both utilities were confronted with long-term challenges that stemmed from financial constraints.

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[259] Blunt, Gold, and Smith, "PG&E: Wired to Fail."

[260] Macwilliams, Monaca, and Kobus, "PG&E: Market and Policy Perspectives on the First Climate Change Bankruptcy," 9,29.

### 3.2.4 Resilience efforts since the Camp Fire

In the year and a half since the Camp Fire and its bankruptcy filing, PG&E has been focused on efforts to increase its resilience to the risk of extreme wildfires that it has been forced to confront. While there have been a number of suggestions for dramatic transformations of PG&E and its electric operations, in order to reduce wildfire risk, these have largely fizzled out.

Instead, PG&E has pursued efforts to build resilience against the two types of extreme wildfire risk that have had the most significant impact on its operations: the physical risks that could cause its equipment to start another catastrophic blaze, and the risks that legal liability from more wildfires could once again place it in acute financial jeopardy.

PG&E's efforts to increase its resilience against physical risk has taken the form of a massive campaign of inspections, repairs, and upgrades, all intended to reduce the likelihood of an equipment-caused fire while simultaneously enabling its electric system to fail gracefully and recover quickly in the face of catastrophic fires. Its efforts to reduce the impact of another surge in legal liability have come in the form of a $21 billion Wildfire Fund, designed in partnership with the State Legislature and the Governor, which is intended to offer a backstop for electric utilities against the sort of overwhelming liabilities that sent PG&E into bankruptcy.

In the wake of the 2017 and 2018 fires, legislation was passed requiring the major California electric utilities to submit detailed Wildfire Mitigation Plans (WMPs) laying out the efforts they planned to take to build resilience against wildfire risk. The first round of WMPs were submitted in 2019, and the 2020 WMPs were conditionally approved by CPUC on May 7, 2020, pending a formal June 11th vote of the full commission.[261] PG&E's WMP offers a great deal of insight into the steps that it has taken over the past year and a half to increase the physical resilience of their electric systems against wildfire risk.[262]

In 2019, PG&E conducted aerial and visual inspections of all of its more than 700,000 electric system structures that are located in what CAL FIRE refers to as High Threat Fire Districts (HTFDs) — areas of elevated wildfire risk, shown in Figure 14. This included 49,715 transmission structures, 694,250 distribution poles, and 222 substations. Based on these

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[261] California Public Utilities Commission, "CPUC Wildfire Safety Division Recommends Approving Utility 2020 Wildfire Mitigation Plans with Conditions."

[262] Pacific Gas and Electric Company, "2020 Wildfire Mitigation Plan," ES-3.

inspections, the utility made 10,841 repairs to electric system components within HTFDs, addressing all of the top-priority ("A-tagged") repairs and 94% of second-priority ("B-tagged") repairs identified as necessary. Per its 2020 plan, the utility intends to restrict inspections to assets located in the top two (of three) HTFD risk tiers, and continue to address all A- and B-tagged repairs.

In addition to examining its own hardware, PG&E conducted an emergency round of "enhanced vegetation management," clearing potential wildfire fuel away from more 2,498 miles of lines and removing 48,000 dead trees — with plans to continue these efforts in 2020, though on a smaller scale.

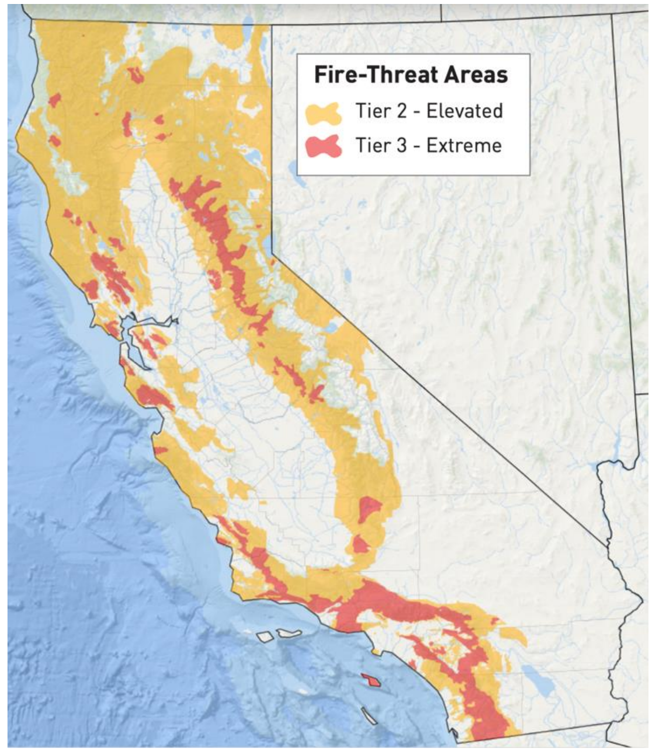

Figure 14. California High Threat Fire Districts (PG&E, via CPUC)

PG&E installed 287 supervisory control devices, intended to prevent recloser devices from reenergizing failed lines in 2019, covering the remainder of its manual recloser inventory. It also installed 298 automated sectionalization devices, with plans to add 592 more in 2020. These devices are intended to help it more precisely deenergize segments of its electric system that face extremely elevated wildfire risks (and will likely enable faster recovery, as well).

The utility also made a significant investment in its wildfire monitoring and prediction capabilities, installing hundreds of weather stations and cameras in HTFDs. It established a brand-new meteorology team and Wildfire Safety Operations Center, which performed a "thirty-year climatology analysis… to determine historical relationship between wind and electrical outages, as well as correlate historic fire records with weather conditions, topography and vegetation." PG&E notes that it produced wildfire risk and weather forecasts for its HTFDs at a 3 km by 3 km resolution in 2019, which it plans to reduce to 2 km by 2 km in 2020.[263]

From these statistics, we can see that PG&E has embarked on a fairly robust campaign of physical wildfire risk mitigation since the end of 2018. Its efforts have included safety-focused, system-wide programs of inspections, equipment repairs, and vegetation management. In addition, it has also invested in more strategic, resilience-oriented efforts — including grid isolation and controls technologies, expanded system monitoring capacity, and the creation of a substantial extreme weather, wildfire, and climate risk prediction and management capability. Altogether, CPUC estimates that the utility's ongoing WMP activities will cost an average of $3.18 billion over the three years from 2020-2022.[264]

However, these commendable efforts still leave a number of challenges insufficiently addressed. CPUC's approval of PG&E's WMP was not an unreserved "Full Approval" but a conditional one. The Commission identified 28 key areas of concern, where it felt that PG&E's WMP was "lacking or flawed" or provided "insufficient detail or justification," and required that the utility address the deficiencies.

Many of these areas of concern are quite familiar to us, at this point. CPUC noted that PG&E had a roughly 50% higher rate causing fires due to equipment failure than SCE and SDG&E.[265] It once again faulted PG&E's antiquated record keeping systems, some of which still remain paper-based. And it raised concerns about the quality of PG&E's vegetation management programs, a lack of clarity in the way it was classifying wildfire risks, and inconsistent prioritization of wildfire risk mitigation efforts.[266]

It also remains to be seen how the unprecedented disruption caused by the COVID-19 pandemic will affect PG&E's wildfire risk mitigation efforts. In its Q1 2020 earnings presentation, released at the beginning of May, PG&E reported that it had met 16% of its sectionalization target for 2020, 19% of its system hardening target, and 32% of its enhanced vegetation management target.[267] In a quarterly update filed with CPUC a day before its earnings were released, PG&E assessed that its wildfire risk mitigation progress was

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[263] Pacific Gas and Electric Company, ES-12, 5-40.
[264] California Public Utilities Commission, "Resolution WSD-003: Ratifying Action of the Wildfire Safety Division on Pacific Gas and Electric Company's 2020 Wildfire Mitigation Plan Pursuant to Public Utilities Code Section 8386," 4.
[265] California Public Utilities Commission, A4.
[266] California Public Utilities Commission, A7, A12.
[267] Pacific Gas and Electric Company, "2020 First Quarter Earnings," 5.

"generally on track" as of the end of the first quarter of the year. However, it also noted that its "workplan incorporates a planned ramp up from the first quarter into increased work completion pace in the second and third quarter of the year."[268] While CPUC instructed PG&E that it "expects the electrical corporations to make every effort to keep WMP implementation progress on track" and "to continue to prioritize essential safety work," the actual impact on PG&E's WMP activities is still unclear.

While PG&E, under the supervision of CPUC, has been working to build resilience against physical wildfire risk, it is also taking part in a first-of-a-kind statewide effort to reduce the risk that legal liability from wildfires could place it, or other California electric utilities, in deep financial jeopardy. This effort has taken the form of a novel piece of legislation which aims to create a financial backstop for electric utilities.

In July of 2019, California's state legislature passed A.B. 1054, which included a number of changes to the state's legal treatment of wildfire risks. Most notably, it created a $21 billion Wildfire Fund that is intended to help electric utilities deal with the costs of wildfires caused by their equipment — the very same that sent PG&E into bankruptcy. First introduced in February 2019, the legislation was passed just in time to avoid a threatened July 2019 downgrade of SCE and SDG&E's credit ratings by Standard and Poor's and other rating agencies, which had already downgraded them in 2019, citing severe liability risks from wildfires. While participation in the fund was offered to all California electric utilities, only PG&E, SCE, and SDG&E elected to join.

The legislation gave the utilities two options for how the fund would be structured. The first, known as the "liquidity option" offered the utilities what was essentially a $10.5 billion revolving credit line — a lending facility that they could tap into in the event that they faced mounting losses.

The lending facility would be funded by an annual charge collected from ratepayers. In order to avoid actually raising electricity rates for consumers, the annual charge takes the place of an existing charge that was set to expire in 2020. Known as the "DWR charge," it raised funds from ratepayers to support the repayment of money the utilities owed

[268] Pacific Gas and Electric Company, "Quarterly Advice Letter Pursuant to Assembly Bill 1054 Regarding the Implementation of Its Approved Wildfire Mitigation Plan and Its Safety Recommendations," April 30, 2020.

California's Department of Water Resources, for helping pay for the costs of power during the 2000/2001 electricity crisis.[269]

However, while the liquidity facility was capitalized using ratepayer money, the utilities would be held responsible for paying back the money they were loaned for wildfire-related expenses within six months: either by seeking CPUC's approval to pass costs along to ratepayers, or by having their shareholders foot the bill.[270]

This structure raised a number of concerns among utilities. As the 2017 Witch Fire case showed, however, CPUC has taken a fairly firm stance on the "just and reasonable" standard for approving rate hikes as a result of utility-caused wildfires. Given this, there was concern among the utilities that CPUC's unwillingness to allow cost pass-through to ratepayers might leave shareholders on the hook. In addition, there was concern that $10.5 billion might not be enough to cover another truly catastrophic wildfire season — especially ones like 2017 and 2018, which saw significant fires in both Northern and Southern California.

As a result, SCE and SDG&E both opted into the second proposed structure, creating the $21 billion fund currently in existence.

The current structure has two major components: an initial payment of $7.5 billion, to be made by the end of 2019, and annual payments of $902 million which continue through 2035. The costs of both the initial and annual payments are to be split among the utilities using a "wildfire allocation metric" — essential a fixed ratio, based on historical factors set out by A.B. 1054 and CPUC, which assigns 64.2% of the costs to PG&E, 31.5% to SCE, and 4.3% to SDG&E.

The initial payments, to be funded by the utilities and their shareholders, were made by SCE and SDG&E last year, while PG&E has been given until it exits bankruptcy to make its initial payment.

The annual payments will be funded by a combination of shareholder and ratepayer funds. CPUC authorized the utilities to impose an annual charge on ratepayers equivalent to the aforementioned DWR charge, with the total funds raised by 2035 not to exceed $10.5 billion, while also authorizing the issue of new debt to pay for the shareholder contribution.

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[269] California Public Utilities Commission, "Decision 19-10-056: Approving Imposition of a Non-Bypassable Charge to Support California's Wildfire Fund and Adopting Rate Agreement Between the California Department of Water Resources and the California Public Utilities Commission."

[270] A.B. 1054 - Public utilities: wildfires and employee protection, sec. 3291.

Altogether, the utilities and their shareholders will contribute $10.5 billion to the Wildfire Fund, with another $10.5 billion raised from ratepayers. The utilities were also required make a combined $5 billion in wildfire safety investments, divided amongst the them per the wildfire allocation metric, the costs of which could not be passed on to shareholders.[271]

In order to actually access money from the Fund to pay off liabilities stemming from wildfires caused by their equipment, utilities will have to meet a number of conditions. First, they must have made their initial contributions in a timely manner — which, for PG&E, means that it must meet its target of exiting bankruptcy proceedings by the end of June 2020. Second, they must annually receive a safety certification from CPUC, based on a number of wildfire risk and organizational management criteria, which all three have successfully done.[272,273,274] And third, the utility must absorb the first $1 billion of wildfire-related liabilities (or the total amount of its mandated wildfire insurance coverage, whichever is greater), before it can tap into the Wildfire Fund.

If the utility's behavior leading up to a wildfire caused by its equipment is deemed "just and reasonable," it does not have to repay the money it received from the Fund. However, in a move that has been criticized by ratepayer advocates, A.B. 1054 shifts the burden for establishing that a utility acted in a "just and reasonable manner," from the utility to outside intervenors. Where the utility previously had to affirmatively prove that it had acted in a "just and reasonable manner," the burden now falls on others to show that it did not.

Even if the utility fails to meet the "just and reasonable" standard, under a provision established by A.B. 1054, it only has to repay an amount equivalent to 20% of its regulator-approved transmission and distribution rate base.

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[271] A.B. 1054 - Public utilities: wildfires and employee protection, sec. 8386.3.

[272] California Public Utilities Commission, "Initial Safety Certification for Pacific Gas and Electric Company," August 23, 2019.

[273] California Public Utilities Commission, "Initial Safety Certification for Southern California Edison Company," July 25, 2019.

[274] California Public Utilities Commission, "Initial Safety Certification for San Diego Gas and Electric," July 26, 2019.

For context, per PG&E's filings in its 2019 rate cases, its transmission rate base under FERC regulation is approximately $8 billion and its distribution rate base under CPUC authority is $16.9 billion, for a total transmission and distribution base of $24.9 billion.[275,276]

This means that even if PG&E failed to prudently operate its electric system, causing a wildfire, the maximum amount that it would have to repay to the Wildfire Fund would be no more than $4.98 billion. For context, recall that the Camp Fire alone caused an estimated $16.5 billion in damages — more than three times the $4.98 billion/20% cap established under A.B. 1054.

However, this safe harbor provision wouldn't apply if PG&E either failed to maintain a valid safety certification with CPUC, or acted with a "conscious or willful disregard of the rights and safety of others."

Assuming PG&E exits bankruptcy protection on schedule later this year, it appears that it will be emerging to find itself with significantly greater financial and legal resilience than it entered with. The combination of the financial backstop provided by the Wildfire Fund, the 20% liability cap, and the shifted burden of proof all offer PG&E a significant buffer against future wildfire liabilities. While the Fund doesn't entirely shield PG&E from liability, it dramatically reduced the financial risks the utility is exposed to, in addition to making them more predictable.

When we consider the significant investments PG&E has made in physical wildfire risk management, and the new financial protections it will receive under A.B. 1054, it is clear that the utility has dramatically increased the resilience of tis electric system to wildfire risks over the past year and a half. However, while PG&E has made strides towards improving the resilience of its electric system, some of steps have not been without challenges — a fact most clearly seen in the controversy surrounding its first major post-Camp Fire test of resilience: the 2019 wildfire season.

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275 Pacific Gas and Electric Company, "Test Year 2020 General Rate Case Application of Pacific Gas and Electric Company," 52.

276 Pacific Gas and Electric Company, "Form 10-K, Fiscal Year 2019," 93.

### 3.2.5 Test of Resilience: 2019 CA wildfire season

The first major test of PG&E's efforts to increase its electric system's resilience to wildfire risk came with the 2019 fire season, which hit its peak in October.

At first glance, it seems that whatever PG&E did in the runup to the 2019 fire season, it worked. While California saw 7,860 wildfires break out from January to November, the impacts of those fires were far milder. While 1,548,429 acres were burned in 2017 and 1,963,101 acres in 2018, only 259,823 acres were consumed in 2019. Similarly, while 10,280 and 24,226 structures were destroyed in 2017 and 2018, respectively, 2019 saw the loss of a mere 732. And, most heartening, while 47 lives were lost to wildfires in 2017 and 85 in 2018, 2019 claimed only three.[277] And though the failure of a 230 kV PG&E transmission line in Sonoma County has been tentatively implicated in the 77,758 acre Kincade Fire (the CPUC/CAL FIRE investigation remains in progress), not a single 2019 wildfire cracked the lists of California's top 20 largest or deadliest. Compared to the preceding two years, the 2019 California fire season appears to have been a significant reprieve.

However, depending on your perspective, the 2019 fire season was either the result of a resounding success for PG&E's wildfire risk mitigation efforts, or a fundamental indictment of its ability to safely *operate* its electric system.

We found that PG&E clearly made strides in increasing the resilience of its system — the ability to predict and withstand extreme weather, fail gracefully, and recover quickly. However, PG&E's approach to the 2019 fire season was characterized — at least in the eyes of the public — not by the fires it prevented, but by the number of times it was forced to cut power to millions of Californians, in order to do so.

We find that the Public Safety Power Shutoffs (PSPS), as the preemptive deenergizing of various parts of PG&E's service area during high wildfire risk periods were called, were likely quite successful in preventing its equipment from sparking catastrophic wildfires as it did in 2017 and 2018. However, PG&E's reliance on the relatively crude tool of temporarily shutting off power to regions that are at risk reveals both the difficulty of dealing with extreme wildfire risks, and the challenges that the utility still faces.

While the concept of shutting off power to prevent wildfires has been around in California in various forms since the 1980s, SDG&E was the first utility to implement the

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[277] California Department of Forestry and Fire Protection, "2019 Fire Season."

modern incarnation of the Public Safety Power Shutoff. In concert with CAL FIRE and CPUC, SDG&E adopted systematic plans for PSPSs after the devastation that that the 2007 fire season (including the Witch Fire) wrought across its Southern California service territory. However, it didn't actually conduct a PSPS until 2013, and its largest shutoff to date only affected 20,800 people.

PG&E began adopting the use of PSPSs in the wake of the devastation — and massive liability burden — it faced following the 2017 fire season. Its first PSPS, conducted in October 2018 as Diablo winds reached up to 50 mph in Northern California wine country's Napa Valley, cut off power to around 60,000 people in small communities scattered across seven counties in — with the shutoffs lasting as long as two days in some places. The utility was heavily criticized for difficulties communicating with local residents and authorities, some of which were the inadvertent result of its own actions. When the power went out in many communities, it also knocked out communication — including with PG&E. Sierra County, which relies on an electricity-dependent Voice over IP (VOIP) phone system, lost its ability to send a reverse 911 alert to residents when the power was cut. [278]

In the wake of the 2018 PSPS pilot, PG&E sought to address the complaints it received about the disruption caused by the shutoffs. It announced that going forward, it would create what it dubbed "resilience zones" in central areas of communities affected by the power shutoffs, delivering mobile generators to serve critical electrical needs including those of "medical baseline" customers, who rely on electricity for vital medical functions and qualify for discounted rates. The utility also announced plans to do nearly 350 community meetings and drills with residents and local residents in the HTFDs that were likely to be impacted by PSPS events.

By the end of April 2019, PG&E was telling reporters that it might have to cut power as much as an eighth of California's 39.5 million residents for up to five days, in an effort to prevent its equipment from sparking destructive and deadly wildfires. Its 2019 Wildfire Safety Plan expanded the region that could be subject to a PSPS to encompass nearly all of the utility's 77,000 square mile service, while noting that the focus remained on the roughly 5.4 million people it served in HTFDs.[279]

[278] Gold and Blunt, "PG&E's Radical Plan to Prevent Wildfires."
[279] Pacific Gas and Electric Company, "Amended 2019 Wildfire Safety Plan."

The utility justified the sweeping move as a matter of prudent over-caution, with Aaron Johnson, the PG&E vice president in charge of the PSPS program, contending, "We simply don't have the luxury, given the extreme weather conditions we are seeing, to wait to get it perfect." CPUC justified the proposals as a regrettable, but necessary measure — arguing that while it would have been ideal if the shutoffs weren't required to begin with, the Commission was committed to regulating them to ensure they were properly carried out.[280]

| PSPS Dates | Customers impacted | Customers impacted w/o notification | Customers impacted w/o notification (%) | Medical baseline customers impacted |
|---|---|---|---|---|
| June 7-9 | 22,474 | 1,500 | 6.7% | 1,571 |
| September 23-25 | 70,826 | 2,000 | 2.8% | 4,410 |
| October 5-6 | 11,609 | 1,400 | 12.1% | 684 |
| October 9-12 | 735,440 | 23,000 | 3.1% | 30,301 |
| October 23-25 | 178,800 | 2,100 | 1.2% | 7,939 |
| October 26 & 29 | 976,700 | 22,000 | 2.3% | 35,950 |
| November 20-21 | 49,000 | 800 | 1.6% | 2,432 |

Table 2. Customer impacts of PG&E PSPS events, 2019[281]

The regulatory disclosures that PG&E was required to file with CPUC offer a glimpse into the seven PSPS events that the utility carried out in 2019, shown in Table 2.

PG&E's first PSPS event of the year occurred in June 2019, impacting less than 23,000 customers in the northern San Francisco Bay area and the Sierra Nevada foothills.[282] After a lull throughout most of the summer, the fall fire season began in earnest, and PG&E responded with near-weekly PSPS events. The utility once again imposed rolling power cuts in the North Bay and Sierra foothills in late September,

[280] Gold and Blunt, "PG&E's Radical Plan to Prevent Wildfires."
[281] Data from the PG&E regulatory disclosure letters to CPUC cited below.
[282] Pacific Gas and Electric Company, "Updates To Post-PSPS Event Reports for June 7-9, 2019."

affecting more 70,000 residents.[283] The smallest PSPS event of the year took place from October 5-6, affecting just over 11,600 residents of Butte, Yuma, and Plumas counties.[284]

Later that week, PG&E began a series of rolling PSPS outages that were the largest in California history at the time. From October 9-12, the utility cut power to 735,440 customers — an estimated 2 million people — in "35 counties across the Sacramento Valley, Sierra Foothills, North Bay, South Bay, East Bay, Central Coast, and parts of Southern California."[285]

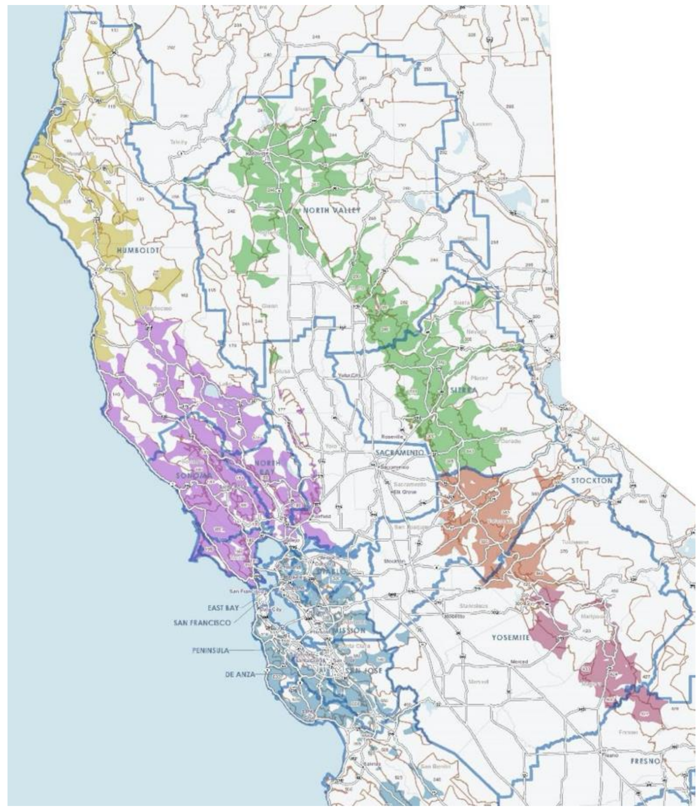


Figure 15. Areas impacted by October 26, 2019 PSPS. Colored areas indicate outage extent, blue lines mark PG&E regional boundaries. (PG&E)

Nearly two weeks later, the utility would conduct a PSPS outage from October 23-25th, which affected 178,800 customers in the North Bay, Sierra foothills, and part of the South Bay. While this was less than a quarter of the size of the preceding outage, it was still larger than every other preceding PG&E PSPS event combined.[286]

Just a day later, PG&E embarked on the first of two back-to-back PSPS events that would together become the largest preemptive power outage that California has seen to date.

In the days leading up to the October 26th and October 29th PSPS events, NWS forecasts as well as PG&E's own internal weather forecasting began projecting that two successive Diablo wind events would soon strike Northern California. The winds were projected to exceed nearly every other event in PG&E's painstakingly assembled 30-year

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[283] Pacific Gas and Electric Company, "Updates To Post-PSPS Event Reports for September 23-25, 2019."

[284] Pacific Gas and Electric Company, "Correction to Updated Post-PSPS Report for October 5-6, 2019."

[285] Pacific Gas and Electric Company, "Amended PSPS Report to the CPUC - October 9-12, 2019 De-Energization Event."

[286] Pacific Gas and Electric Company, "Amended PSPS Report to the CPUC - October 23-25, 2019 De-Energization Event."

record, with windspeeds reaching up to 100 mph in certain regions — equivalent to a Category 2 hurricane. The NWS issued a Red Flag warning for nearly all of Northern California's interior, while PG&E noted that the windstorms "likely will be stronger than the October 2017 northern CA fire event," and warned that "this event has potential and energy to be the strongest in years."[287]

The utility's concern about wildfire risk stemmed not only from the forecasted strength of the two Diablo wind events, but also from the fact that they would be coming in as a one-two punch, following on the heels of a series of successive "dry offshore wind events" which had already left potential wildfire fuels "critically dry and receptive for fire." PG&E viewed this combination of extremely high winds, low humidity, and "critically dry" fuels as the recipe for a potential disaster that could rival even the October 2017 wine country fires.

In response, the utility began a series of rolling PSPS outages that would ultimately affect 976,700 customers (an estimated 2.5 million people) across Northern California, as shown in Figure 15.

The October 9-12 and October 26/29 PSPS events were met with a great deal of public controversy, largely centered around a perceived lack of adequate communication and coordination with the affected communities. Over the course of the three events, over 45,000 people experience preemptive power shutoffs without being notified by PG&E, as shown in Table 3. However, it's worth noting that only 3.1% of those affected by the October 9-12 PSPS failed to receive a notification from PG&E, a rate that dropped to 2.3% for the October 26/29 events. (And, a marked decline from the rates of 6.7% and even 12.1% seen in previous PSPS events.) Another common concern was the impact on medical baseline patients, more than 30,000 of whom lost power in each of the two series of PSPSs.

However, even in the face of these critiques, PG&E did demonstrate the value of some of the resilience measures it had worked to put in place since the Camp Fire. The 298 automatic sectionalization devices that were installed as part of PG&E's 2019 Wildfire Safety Plan proved their worth, by giving the utility more granular control over PSPS outages, allowing it to more finely target the lines and regions it deenergized. According to PG&E's estimates in Table 3, the sectionalization of 449 circuits prevented a total 796,836 customers (over 2 million people) from losing their power during the 2019 PSPS events.

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[287] Pacific Gas and Electric Company, "Amended PSPS Report to the CPUC - October 26 & 29, 2019 De-Energization Event," 34–35.

| PSPS Dates | Circuits sectionalized | Impact reduction from sectionalizing (customers) | Damage/hazards identified |
|---|---|---|---|
| June 7-9 | 7 | 8,500 | 3 |
| September 23-25 | 19 | 21,984 | 4 |
| October 5-6 | 4 | 8,200 | 2 |
| October 9-12 | 50 | 77,152 | 116 |
| October 23-25 | 65 | 93,000 | 26 |
| October 26 & 29 | 265 | 533,000 | 554 |
| November 20-21 | 39 | 55,000 | 15 |

Table 3. Impacts of resilience measures during PSPS events, 2019[288]

There is also evidence to indicate that the shutoffs did potentially prevent the initiation of a number of wildfires over the course of 2019. In disclosures to CPUC, PG&E disclosed that in the wake of the PSPS events, it had identified a total of 720 hazards or instances of damage (shown in Table 3) that could have potentially sparked wildfires — 554 of which occurred during the October 26 & 29 PSPS. Moreover, in response to questioning by the federal court overseeing its post-San Bruno probation, PG&E disclosed that over the course of the October PSPS events, it identified 274 instances of damage to its power lines and other equipment by high winds and vegetation, each of which would likely have produced an electrical arc event capable of starting a fire.[289,290]

The prevention of potentially hundreds of wildfire initiations through Public Safety Power Shutoffs, while reducing the cumulative number of people affected by the outages by more than 2 million, is a compelling argument in favor of giving PG&E a solid passing grade for its first major test of resilience — particularly in light of the dramatic reductions in damage caused by the 2019 fire season, compared to those of 2017 and 2018.

However, the fact remains that the October 26 & 29 shutoff left more than 2.5 million Californians without power for an average of 55 hours each — with some in the dark for almost a week.[291] Systemwide, the PSPS outages lead to a 70-fold increase in the time PG&E

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[288] Data from the PG&E regulatory disclosure letters to CPUC, and *U.S. v. PG&E filings*.
[289] Pacific Gas and Electric Company, “Response to Request for Information on PSPS.”
[290] Pacific Gas and Electric Company, “Response to Questions to PG&E Re: Late October PSPSs.”
[291] Pacific Gas and Electric Company, “2020 Wildfire Mitigation Plan,” ES-9.

customers cumulatively spent in planned power outages, from an average of 1.4 million hours per year in 2015-2017, to 101.2 million hours in 2019.[292] While it appears clear that PG&E's efforts to build the resilience of its system paid off in the form of dramatically lower wildfire damages in 2019, it is fair to question whether repeatedly plunging millions of residents into the dark — even in the face of record extreme weather — truly ought to be considered resilience. Though PG&E appears to have passed the test of resilience set before it in 2019, it is clear that the utility has a long road ahead of it when it comes to comprehensively combatting the risk of extreme wildfires that it will continue to face in the years to come.

[292] Pacific Gas and Electric Company, Attachment 1-Table 2(3a).

## 3.3 New York & New Jersey (2012-2020)

*I've seen the lights go out on Broadway*
*I saw the Empire State laid low…*

*They turned our power down*
*And drove us underground*
*But we went right on with the show*

– Billy Joel, 1976 [293]

Having examined the body blow sustained by Puerto Rico after Hurricane Maria, and the ongoing effort to combat Northern California's wildfires, we now turn our attention to the oldest of our case studies: a "Superstorm" that made a sudden left turn towards the nation's largest metropolitan area — and in the process, appears to have served as a wake-up call that not only led to a remarkable focus on building resilience into the region's electric systems, but served as the foundation of a major push for resilient decarbonization.

When it made landfall on the Jersey Shore and sent a storm surge up Wall Street in late October 2012, Superstorm Sandy became a turning point for the New York/New Jersey region — one of those "holy shit"/"no more" moments we've previously discussed.

The storm was devastating, there's no doubt about it. Sandy claimed 157 lives in the United States. It caused $65 billion in damage across the East Coast, including roughly $32 billion in New Jersey and $30 billion in New York State — with around $19 billion of that in New York City alone. And at its peak, it left 8 million people without electricity, including 4.6 million in New York and New Jersey — some of whom wouldn't get their power back for nearly two weeks. But with the help of a massive mutual assistance effort from across the U.S., the region's utilities restored service faster than average. And with the help of more than $50 billion in federal funding, the region — and its electric systems — began to rebuild.

What interests us most about Sandy isn't the damage it did to electric systems, but rather the key lesson that utilities, regulators, and state governments took away in its aftermath: this is a preview of a future that can't be hardened against, but rather must be met with proactive resilience. The aftermath of the storm saw a remarkable string of utility investments, regulatory precedent, and governmental policies that offer one example of what a disaster-catalyzed push for resilient decarbonization can look like.

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[293] Joel, *Miami 2017 (Seen the Lights Go Out on Broadway)*.

### 3.3.1 Superstorm Sandy

Much like Hurricane Maria, Hurricane Sandy had its origins in a late-fall tropical wave off the western coast of Africa, this one first detected by the NHC on October 12, 2012. However, Sandy took a much slower, more meandering path towards its ultimate destination.

From October 12th through October 22, the "disorganized" wave meandered across the Atlantic, crossing below the islands of Puerto Rico and Hispaniola into the southern basin of the Caribbean Sea.[294] There, it strengthened into what the NHC dubbed "Tropical Depression Eighteen."[295] Over the course of the 22nd and 23rd, Eighteen made a small loop in the southwestern Caribbean, before strengthening into Tropical Storm Sandy, the eighteenth named storm of the 2012 Atlantic hurricane season.

However, unlike Maria (which went from tropical storm to Category 5 hurricane in just over 24 hours), Sandy had a much slower initial intensification — gaining just 11 mph in wind speeds from the 23rd to the 24th. The storm strengthened into a Category 1 hurricane, with its peak winds measured at 86 mph just before it made landfall over the southeastern corner of Jamaica on the afternoon of October 24th. As the NHC noted in its meteorological history of the storm, "the brief passage over Jamaica did not seem to affect Sandy much." The storm passed over "the deep warm waters of the Cayman Trench," where it reached its peak strength — a Category 3 hurricane, with winds measured at 115 mph as it made landfall in southeastern Cuba early on the morning of October 25th. Its five-hour journey across Cuba briefly weakened Sandy to tropical storm status, and sent it on a curving northward path that threaded between the islands of the Bahamas.

It is here that Sandy first began to take on one of the characteristics that made it so destructive: its size. As it crossed from Cuba to the Bahamas, it passed over the warm Gulf stream current, which spread it out — nearly doubling its size by the 27th. Its maximum winds extended for a radius of more than 100 miles, which the NHC described as "quite unusual." Deflecting eastward away from the Bahamas and the Florida coast, Sandy (once again a hurricane) moved further out into the Atlantic — continuing to grow in size as it paralleled the East Coast over the course of the 27th and 28th.

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[294] Blake et al., "Tropical Cyclone Report: Hurricane Sandy," 1.
[295] Lacey, "Resiliency: How Superstorm Sandy Changed America's Grid," 11.

Throughout its progression thus far, Sandy had confounded weather forecasters, with projected storm tracks varying wildly. Some initial forecasts had the storm veering off into the Atlantic after crossing over Cuba, while others saw it continuing to meander a few hundred miles off the East Coast until it faded away. However, by the 27th, most of the forecasts had converged on a startling conclusion — the storm would make a sharp left turn sometime on October 29th, sending it hurtling towards the Jersey Shore at peak high tide.[296,297] Forecasters at the NHC warned that there were no "modern precedents for what the models are suggesting."[298]

Sandy's "left turn," as it came to be known, was driven by two major meteorological forces. First was what the NHC described as "an anomalous blocking pattern over the North Atlantic" — a high-pressure system that was preventing the storm from coasting out into the Atlantic. While the North Atlantic high was pushing Sandy towards the East Coast, a winter storm/cold front developing over the central United States — a low pressure system — began pulling Sandy in as well. This barometric forcing, or pressure gradient, created the conditions that caused Sandy to swerve towards New Jersey.

Over the course of October 29th, Sandy re-intensified into a Category 2 hurricane, with winds hitting 97 mph, while growing to its maximum size of more than 1000 miles across — "an extraordinarily large hurricane," in the NHC's words. Weakening slightly as it merged with the winter storm system, Sandy[299] slammed ashore just after 8:30 p.m. EDT on October 29th, making landfall just north of Atlantic City, in the shore town of Brigantine, and heading inland.[300]

While Sandy was aimed at the southern Jersey Shore, its impacts were profoundly felt across New Jersey and New York — particularly in the New York/NJ metropolitan area to the north. Due to Sandy's immense size, hurricane-force winds gusting up to 89 mph were felt across northern New Jersey, New York City, and Long Island.[301]

At the same time, the confluence of a high tide with the storm's landfall sent devastating storm surges racing across the Jersey Shore, and up into New York Harbor. Tidal

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[296] Lacey, 12.
[297] Blum, *The Weather Machine: A Journey Inside the Forecast*, 7-8,10.
[298] Lacey, "Resiliency: How Superstorm Sandy Changed America's Grid," 13.
[299] Technically a "post-tropical" or "extratropical" cyclone at this point, Sandy had the strength of a Category 1 hurricane.
[300] Blake et al., "Tropical Cyclone Report: Hurricane Sandy," 3–4.
[301] Blake et al., 5.

gauges at the Battery on the southern tip of Manhattan, where records date back to 1920, measured a 14.06-foot storm surge — 4.36 feet above the previous record, and 4.55 feet above the surge seen during Hurricane Irene the previous year. Meanwhile in New Jersey, surges caused 7-9 feet of flooding along the Jersey Shore, while across the Hudson River from New York City, flood levels of 4-6 feet were observed in densely-populated cities like Newark, Jersey City, and Hoboken.[302]

The toll Superstorm Sandy exacted on the East Coast was immense. Across states, it claimed a total of 157 lives. In New Jersey, over 360,000 homes and 19,000 businesses were damaged or destroyed, with damage particularly severe along the Jersey Shore and the state's barrier islands. Along the Hudson, the storm surge flooded Jersey City and rendered half of the city of Hoboken impassable, requiring the deployment of the National Guard to rescue nearly 20,000 residents trapped by the rising floodwaters. In New York, an estimated 305,000 homes were destroyed by the storm surge, with entire blocks of homes on Staten Island and Long Island washed away.[303] The storm also caused $4.8 billion in damage to New York City's subway system.[304]

Since it was technically no longer a tropical hurricane when it hit the New York/New Jersey area, Sandy was quickly renamed by the press and the public. Its movie-monster-like combination of a hurricane-force storm, an Atlantic high, a continental winter storm, and a perfect high tide — as well as its proximity to the Halloween holiday — led a number of media outlets to dub it the "Frankenstorm."

But the nickname that has stuck is one that best captures the enormous impact is had on the region: *Superstorm Sandy*.

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[302] Blake et al., 8–10.
[303] Blake et al., 18.
[304] Hinds, "Totaling Sandy Losses."

### 3.3.2 Superstorm Sandy's impact on electric systems

Superstorm Sandy dealt a significant blow to the region's electric systems, leaving 8 million people across the East Coast without electricity in its immediate aftermath. As shown in Figure 16 (Generated from a review of 33 U.S. D, this included over 2.6 million customers in New Jersey (65% of the state) and nearly 2.1 million people in New York (23% of the state).

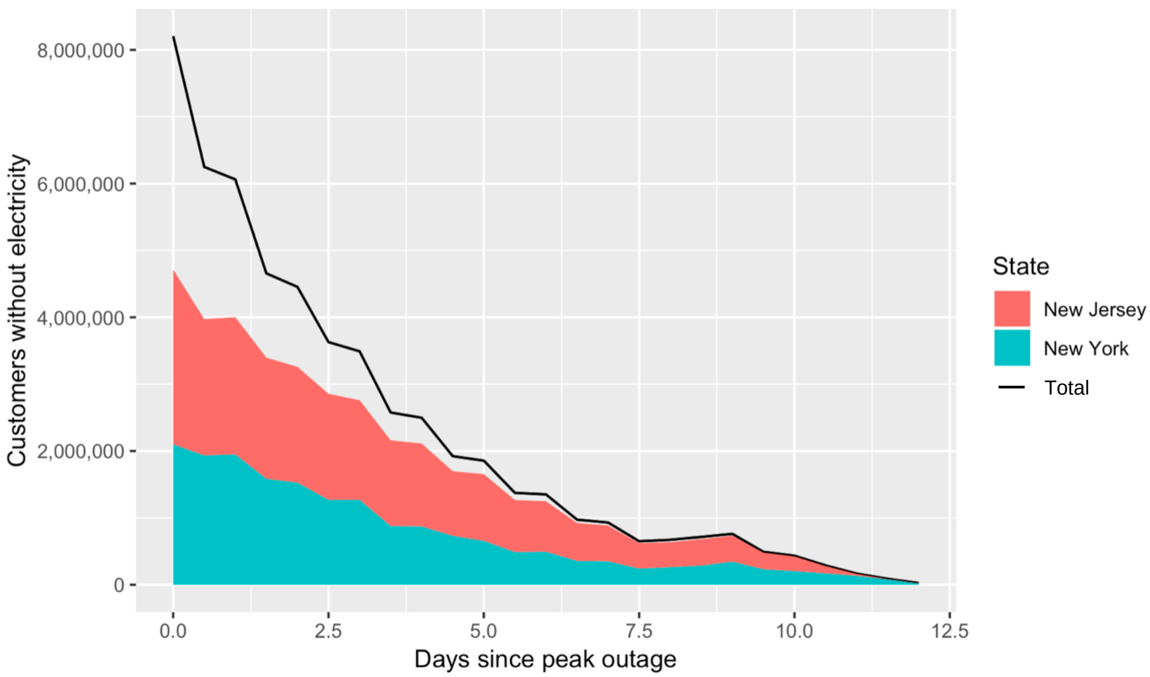


Figure 16. Total, NY, and NJ power outages following Superstorm Sandy

Though local utilities made substantial efforts to protect their electric systems, in advance of the storm, the combination of the record 14.1-foot storm surge, coastal flooding, and high winds caught them by surprised and proved overwhelming. Local utilities Consolidated Edison (better known as ConEd), which serves much of New York City and the surrounding counties, preemptively decided to shut down selected underground transmission and distribution networks in Manhattan and Brooklyn, in an effort "to avoid serious damage to equipment"— a practice it began in the 1990s, after a storm surge destroyed equipment that remained energized.[305] Other utilities across the region did the same, hoping that these efforts would also help speed the eventual restoration of power.[306]

However, ConEd's planning envisioned a maximum 12-foot storm surge, based in part on a historical record set in 1821 — as did the preparations conducted by the Public Service Electricity and Gas Company (PSE&G), the largest electric utility in New Jersey.[307,308]

As a result, many utilities were caught off guard by Sandy's 14.1-foot storm surge and the high winds that accompanied it. ConEd left a key substation on 13th Street in lower Manhattan — which powered the bottom third of the island — energized as the storm rolled in, hoping to minimize the disruption of service to some of its most high-profile customers. However, the flood barriers surrounding the substation only rose 12 feet above the water level, and when the storm surge rolled in from the Battery, the substation failed with "the blinding flash of an explosion," plunging America's "most famous skyline" into darkness.[309,310]

ConEd's surprise at the storm's devastating impact was palpable in an after-action report it submitted to NERC, noting that "The toll the storm took on our electric systems was astounding." The damage was significant, with the storm surge, wind, and flooding destroying five transmission substations, 4 GW of generation, over 900 transformers, and 1000 distribution poles. Altogether, the storm knocked 70% of ConEd's overhead distribution system offline, as well as more than fifteen of its transmission and distribution networks across Manhattan, Brooklyn, and Staten Island.[311] Altogether, "about one-third of Con Edison's customers — 1,115,000 out of 3.3 million — lost power."[312]

Elsewhere in New York, Long Island Power Authority (LIPA), a publicly-owned utility operated by the investor-owned utility National Grid, saw 1.1 million (nearly 90%) of its Long Island customers lose power.[313] LIPA, which would be near-universally criticized for insufficient preparation and mismanaged recovery efforts, "experienced damage to 50 substations, 2,100 transformers, and 4,500 utility poles following Sandy."[314] Within a year,

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305 Lacey, "Resiliency: How Superstorm Sandy Changed America's Grid," 19.
306 North American Electric Reliability Corporation, "Hurricane Sandy Event Analysis Report," 5.
307 Van Nostrand, "Keeping the Lights on during Superstorm Sandy," 101.
308 Lacey, "Resiliency: How Superstorm Sandy Changed America's Grid," 27.
309 Lacey, 19.
310 Van Nostrand, "Keeping the Lights on during Superstorm Sandy," 101.
311 North American Electric Reliability Corporation, "Hurricane Sandy Event Analysis Report," 13.
312 Van Nostrand, "Keeping the Lights on during Superstorm Sandy," 101.
313 Van Nostrand, 102.
314 Office of Electricity Delivery and Energy Reliability, "Comparing the Impacts of Northeast Hurricanes on Energy Infrastructure," 14.

New York Governor Andrew Cuomo would strip control of LIPA from National Grid, on the basis of its poor handling of Sandy, and award it to PSE&G — a radical proposal, made in an effort to shock the utility into cleaning up its act, and followed through upon with the hope of helping LIPA turn over a new leaf.[315]

The damage was equally severe in New Jersey, where 90% of PSE&G's customers lost power as the utility experienced damage to 31 substations and 1,000 transformers. Jersey Central Power and Light (JCP&L), the state's second-largest utility, also experienced severe outages following the loss of 3,400 sections of wire — and, like LIPA, would be roundly criticized for a slow, ineffective response and failing to communicate adequately with customers and local municipalities.[316]

A number of the utilities had already invested in vegetation management and the replacement of older transmission and distribution lines, in the wake of Hurricane Irene — which made landfall in the region as a tropical storm in August 2011, but still managed to cut power to around 4 million people. However, Sandy — a much stronger storm — had much more significant impacts on electric systems, with PG&E, and LIPA reporting that it caused roughly double the physical damage of Irene, and ConEd noting that it "lost 10 times as many poles, more than five times as many transformers, and more than four times as many miles of cable." Nevertheless, it still damaged some of the same equipment that had been repaired after Irene, which remained insufficiently protected against flooding and storm surges.[317,318,319]

As shown in Figure 17, electric systems' recovery from Superstorm Sandy took roughly twice as long as their recovery from Hurricane Irene. After Irene, 95% of customers had their power restored within about 5 days, as seen in Figure 17, while it took roughly 10 days to reach that level after Sandy. Restoration times varied by location, as seen in Figure 16: New Jersey reached 95% restoration within 10 days, while New York as a whole only took a week. However, parts of Long Island (including much of LIPA's service area) took 12-14 days to reach that level.

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[315] Tweed, "PSE&G Takes Over LIPA Operations."
[316] Office of Electricity Delivery and Energy Reliability, "Comparing the Impacts of Northeast Hurricanes on Energy Infrastructure," 9–10.
[317] Office of Electricity Delivery and Energy Reliability, 13–14.
[318] Van Nostrand, "Keeping the Lights on during Superstorm Sandy," 102.
[319] Lacey, "Resiliency: How Superstorm Sandy Changed America's Grid," 6,14, 28.

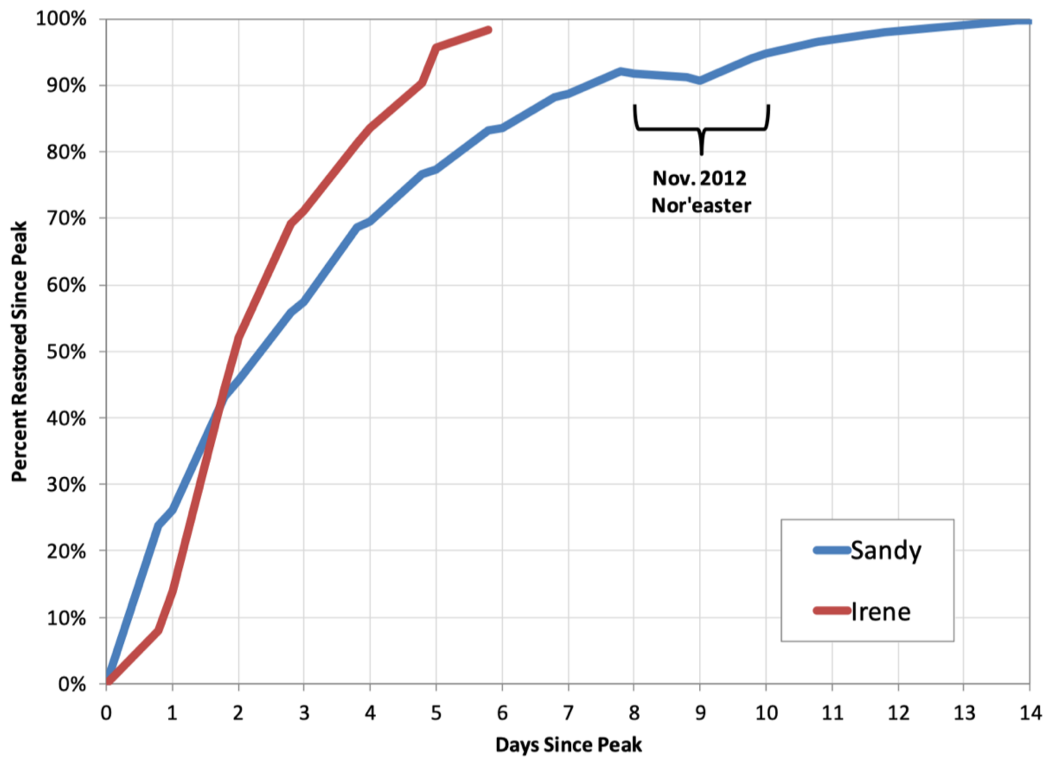


Figure 17. Electric service restorations following Hurricane Irene and Superstorm Sandy[320]

The restoration process was significantly aided by 67,000 workers from around 100 companies, who traveled to the region from 34 states, as well as Canada.[321,322] However, as is evident in both Figure 16 and Figure 17, the progress of the restoration efforts was hindered by a Nor'easter which covered the region in snow and ice, just over a week after Sandy made landfall — increasing the number of outages (including by cutting power to some customers who'd just had it restored to them), and slowing the progress of utility crews trying to restore power.

But even in the face of this follow-on disruption, electric power was almost fully restored across New York and New Jersey within two weeks — with the exception of the hundreds of thousands of homes that had been washed away by the storm.

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[320] Office of Electricity Delivery and Energy Reliability, "Comparing the Impacts of Northeast Hurricanes on Energy Infrastructure," 11.

[321] North American Electric Reliability Corporation, "Hurricane Sandy Event Analysis Report," 20.

[322] Office of Electricity Delivery and Energy Reliability, "Comparing the Impacts of Northeast Hurricanes on Energy Infrastructure," 19.

### 3.3.3 Climate change and Superstorm Sandy: a wake-up call

Superstorm Sandy served as a wake-up call for the New York/New Jersey region in many ways, but arguably none was more pronounced than the reminder it offered of the growing risks the region faces from climate change.

While hurricanes are no strangers to the region. Prominent hurricanes have been recorded as far back as 1878 in New Jersey, and the Category 3 "Long Island Express" that struck New York in 1938 is among the most devastating extreme weather events to ever strike the region.[323]

That said, hurricane-force storms aren't exactly common in the region — and coming on the heels of the widespread power outages caused by Hurricane Irene just a year earlier, Superstorm Sandy began to feel like the beginnings of a trend.

In our examination of Hurricane Maria in Chapter 3.1.2, we gave extensive discussion to the role that climate change — in the form of warming ocean temperatures — plays in exacerbating the strengths of hurricanes. While findings from Cheng, et al. which we considered demonstrated a broad warming trend across the global ocean, they also found that the waters off the coast of the Northeastern U.S. have experienced some of the most significant warming in the world, as shown in Figure 18.

A joint study conducted in 2019 by the Climate Impact Lab — a partnership between U.C. Berkeley, Rutgers University, the University of Chicago, and the Rhodium Group (a climate/energy analysis consultancy — confirmed these observations, noting that "sea surface temperature in the Northeast US has warmed faster than 99% of the global ocean since 2004, and projections indicate that this area will continue to warm more quickly than other ocean regions through the end of the century."[324]

Based on a review of oceanographic literature, it appears that the accelerated warming of the Atlantic Ocean off the coast of the Northeastern U.S. did play a contributing role in Superstorm Sandy's outsize impact on the New York/New Jersey region. Trenberth, et al. (2015) found that if ocean heat was reduced by an amount commensurate with observed warming to date, Sandy's sustained windspeeds decreased by about 8 mph and its precipitation was reduced by roughly 35%, while noting that the storm surge was increased

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[323] Rhodium Group, "New Jersey's Rising Coastal Risk," 3.
[324] Rhodium Group, 3.

by roughly 8 inches due to sea level rise — not an insubstantial amount, when we consider that a difference of a few feet was all that it took to inundate ConEd's Lower Manhattan substations.[325] In its complementary work, the Climate Impact Lab found that the increase in sea level caused the storm surge from Sandy "to flood an area 27 square miles greater than it would have in 1880, increasing the number of New Jersey residents living on land lower than the storm tide by about 38,000."[326]

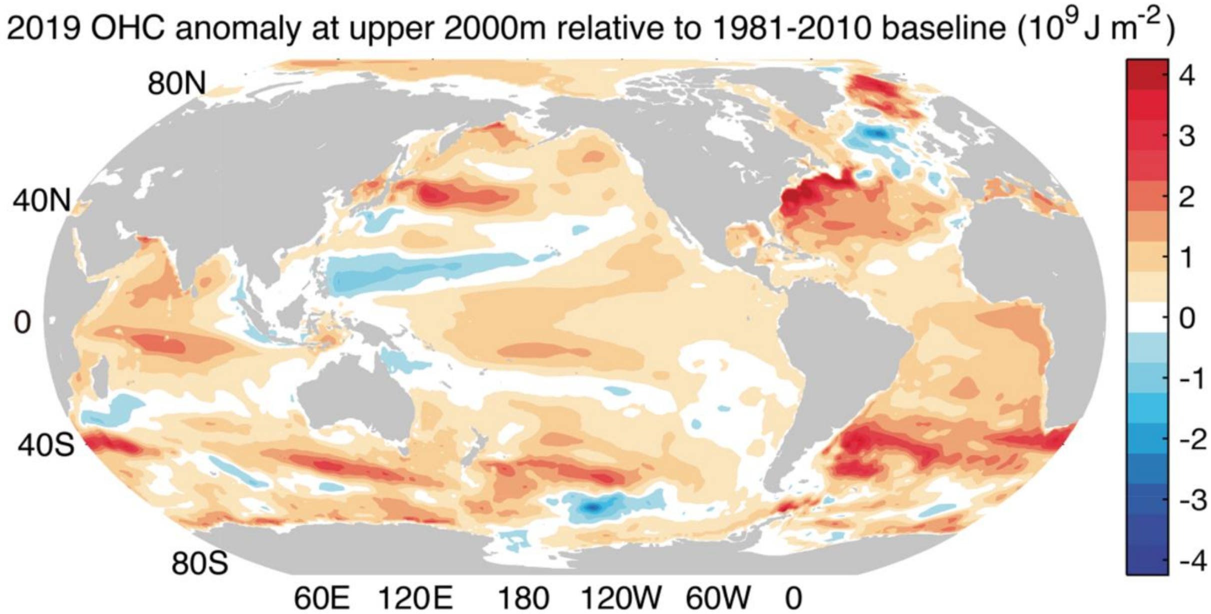


Figure 18. Upper ocean heat content anomaly[327]

In their analysis, which focused on risks to New Jersey, the Climate Impact Lab further warned that Sandy was, indeed, likely a preview of future storms to come. The Lab highlighted the value at stake — noting that the 17 counties that make up the state's 1,792-mile coastline are home to 80% of its population and "more than $400 billion in annual economic output."[328]

Combining this with the growing risks from Atlantic hurricanes, they found that "the expected average annual loss to New Jersey from hurricane-related wind and flood damage

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[325] Trenberth, Fasullo, and Shepherd, "Attribution of Climate Extreme Events."
[326] Rhodium Group, "New Jersey's Rising Coastal Risk," 6.
[327] Cheng et al., "Record-Setting Ocean Warmth Continued in 2019," 138.
[328] Rhodium Group, "New Jersey's Rising Coastal Risk," 3.

today is likely about $670 million to $1.3 billion higher than it would have been if sea levels and hurricane activity in the 1980s remained constant."[329]

This serves to illustrate the particular acuity with which climate change has exacerbated the risk that hurricanes pose to the Northeastern U.S. — particularly the New York/New Jersey region.

[329] Rhodium Group, 10.

### 3.3.4 Resilience efforts since Superstorm Sandy

Unlike in the wake of Hurricane Maria, where merely restoring power to 95% of Puerto Rico's residents took nearly half a year, the two-week restoration that followed Superstorm Sandy to quickly pivot to the challenge of addressing the long-term threats posed by climate change, extreme weather, and the threat of another Sandy-caliber storm.

Remarkably, resilience was part of the response to Superstorm Sandy from a very early stage. Just days after the 113th Congress was seated in January 2013, it passed the Disaster Relief Appropriations Act of 2013.[330] A $50.5 billion package of aid for the victims of Superstorm Sandy, the bill contained $17 billion in funds meant "to meet immediate and critical needs" in the wake of the storm, as well as $33 billion meant to support "longer-term recovery efforts and infrastructure improvements that will help prevent damage caused by future disasters."[331]

Of the $50.5 billion total, roughly $16 billion was allocated to the U.S. Department of Housing and Urban Development (HUD) to be given to the affected states and communities as Community Development Block Grants (CDBGs) — HUD's primary mechanism for funding disaster relief and infrastructure development efforts.[332] In a novel move, HUD preemptively committed to distributing roughly $1 billion of the CDBG money — which, as a block grant, generally comes with much greater flexibility, to the winners of a resilience-focused infrastructure development program.

Launched in June 2013, the Rebuild by Design program sought "to promote innovation by developing regionally-scalable but locally-contextual solutions that increase resilience in the region."[333] It would ultimately fund seven infrastructure development projects across the New York/New Jersey region, each of which sought to protect communities from Sandy-caliber storms, by incorporating key resilience principles like proactive planning, graceful failure, and effective recovery.

The projects included an effort to protect Lower Manhattan against another Sandy-caliber storm surge at the Battery, a combined flood protection and microgrid project in the south Bronx, a series of upgrades intended to prevent Hoboken from flooding as it did during

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330 Public Law 113-2: Disaster Relief Appropriations Act, 2013.
331 Painter and Brown, "FY2013 Supplemental Funding for Disaster Relief," 2.
332 Painter and Brown, 30.
333 U.S. Department of Housing and Urban Development, "Rebuild by Design."

Sandy, and the restoration of wetlands in New Jersey, Long Island, and Staten Island to protect against storm surge and flooding. Ultimately, HUD would award around $930 million to the Rebuild by Design projects, which was slated to be spent by September 2019.

This effort to use the aftermath of Superstorm Sandy to redesign critical infrastructure with long-term resilience in mind wasn't just limited to a (relatively small) segment of the disaster funds: the region's normally staid utilities also got on board, with a little bit of prodding.

In February 2013, PSE&G submitted a proposal for what it called the "Energy Strong" program to its regulator, New Jersey's Board of Public Utilities (BPU). The plan proposed to invest $2.76 billion in electric system upgrades over 10 years, as part of a $3.94 billion effort to build resilience across PSE&G's electric and gas operations — the cost of which would be mostly recovered from ratepayers. The proposal was split into two categories: "system hardening" measures, and efforts "to increase resiliency of the electric delivery infrastructure."

Chief among the proposed system hardening measures was $1.68 billion to protect 34 substations that had been affected by Sandy and Irene, through a combination of installing flood barriers, elevating the substations, and relocating them. Also included were upgrades to transmission and distribution lines, undergrounding of select lines deemed to be at greatest risk, making 200 transformers fully submersible, and relocating emergency operations centers to higher ground.

Highlights of the proposed resilience measures were a $300 million control system expansion meant to give PSE&G the capability to remotely monitor and control all of its transmission and distribution circuits in real-time, and $200 million to increase the number of redundant circuit loops on particularly vulnerable transmission and distribution routes. The utility also proposed a number of upgrades to its internal and external communications systems, to aid in pre- and post-storm coordination, and an advanced distribution management system to aid in the proactive assessment of potential storm damages.[334]

The ambitious plan was quickly met with skepticism by ratepayer advocates and BPU commissioners, who worried that PSE&G was going on a "spending bonanza" at New Jersey

[334] Van Nostrand, "Keeping the Lights on during Superstorm Sandy," 105–6.

ratepayers' expense (instead of protecting the electric system from future storms at the lowest cost), and expressed doubts that another Sandy-caliber storm would occur anytime soon.[335]

After thirteen months of back-and-forth wrangling, PSE&G and the BPU agreed on a scaled-down, $1.22 billion plan that included just $600 million for electric system investments. The BPU also agreed that PSE&G could pursue an additional $220 million in electric system spending through a base rate case — the standard mechanism by which regulated utilities like PG&E can receive permission to raise their electric rates, in order to earn a specified return on their investments.[336] Ultimately, the utility would end up spending $620 million to harden just 29 substations, with its two marquee resilience efforts — the control system upgrade and the redundant circuits — receiving $100 million each.[337]

Meanwhile in New York, ConEd, the PSC, and a group of determined NGOs were about to set a remarkable precedent for how an ordinary electric regulatory process — the rate case — could become a powerful instrument of resilient decarbonization. In January 2013, ConEd submitted a filing for its 2013 general electric, natural gas, and steam rate case that proposed "approximately $1 billion in potential storm hardening structural improvements" to be carried out through 2017, with a commitment to spend a quarter of the funds on "storm protection measures" by the end of 2015. Of the $1 billion total, $800 million was allocated to its electric system.

The storm hardening/protection measures would be "intended to reduce the size and scope of service outages from major storms, as well as to improve responsiveness and expedite the recovery process to better serve [ConEd's] customers," and specifically included "strategic undergrounding and flood protection projects," including flood walls, elevating equipment, and installing submersible equipment.

At the same time, ConEd also proposed "various projects to improve the flexibility of the electric distribution system," specifically referencing the installation of additional switches, "smart grid technology," and the "reconfiguration" of parts of its electrical system to "reduce the impact to customers most affected by certain storms."[338]

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[335] Lacey, "Resiliency: How Superstorm Sandy Changed America's Grid," 55, 57.
[336] Van Nostrand, "Keeping the Lights on during Superstorm Sandy," 107.
[337] Wernsing and Public Service Electric and Gas Company, "Making New Jersey Energy Strong: Reliability & Resiliency in New Jersey," 26.
[338] Consolidated Edison Company of New York, "2013 Electric, Gas and Steam Rate Filing."

After ConEd submitted its filing, a group of environmental NGOs[339] joined the rate case as intervenors, seeking to offer "a different perspective" on how the ratemaking process could help shape ConEd's electric system to be "resilient under conditions that are likely to exist for the next thirty or forty years."

Chief among the intervenors' concerns was the fact that the plan ConEd had set forth in its 2013 filing didn't take into account the growing climate risks that the utility would have to contend with in the coming decades. The plan also failed to comprehensively consider the impacts that climate risks would have on the infrastructure that ConEd was proposing to build, over its expected multi-decadal lifespan.[340] Additionally, the intervenors argued that ConEd's approach to "storm hardening" was a myopic perspective that neglected much of the value that could be realized from resilience-based approaches, including distributed energy resources and microgrids.[341]

In a remarkable turn of events, both the PSC and ConEd found the intervenors' arguments to be quite persuasive. Just over a year later, the PSC issued a final order in ConEd's rate case that has since become the gold standard for driving climate resilience through ratemaking proceedings.

There were three novel components to the PSC's order. First, it noted that ConEd and the NGO intervenors had formed a "Storm Hardening and Resiliency Collaborative," aimed at examining a broader set of resilience-based options to protect ConEd's electric system from future Sandy caliber storms. In approving ConEd's $1 billion investment over four years, the PSC explicitly ordered the utility to work in tandem with the Collaborative to ensure that it was "assess[ing] the relative benefits and costs of resilience of existing utility infrastructure and alternative resilience approaches," with a specific order to consider expanding its use of microgrids and distributed energy resources.[342]

Second, while setting a new standard for resilience, the PSC also broke new ground in climate risk management. The Commission rooted its action in an acknowledgement that "Sandy drove home the urgency not only of emergency preparedness, but of advance planning for the impacts on the utilities of New York State of extreme weather events exacerbated by

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[339] The Environmental Defense Fund (EDF), Natural Resources Defense Council (NRDC), Pace Energy and Climate Center, and Columbia Law School Center for Climate Change Law

[340] Gundlach, "Climate Risks Are Becoming Legal Liabilities for the Energy Sector," 95.

[341] Van Nostrand, "Keeping the Lights on during Superstorm Sandy," 120–21.

[342] New York State Public Service Commission, "Order Approving Electric, Gas, and Steam Rate Plans in Accord with Joint Proposal," 67–68.

a changing climate." It further noted that "changing climate conditions are likely to affect Con Edison's ability to provide reliable service without major disruptions." As a result, the PSC ordered ConEd to consider the "risks and probabilities of future climate events" in all of its future investment decisions. Additionally, it ordered the utility to produce a series of comprehensive assessments of its electric system's short and long-term vulnerability to climate risks and impacts, to culminate in an implementation plan that would address the vulnerabilities.[343]

And third, the PSC applied its new standards for climate risk and impact assessment to all utilities in the state of New York, insisting that "We expect the utilities to consult the most current data to evaluate the climate impacts anticipated in their regions over the next years and decades, and to integrate these considerations into their system planning and construction forecasts and budgets."[344]

In one fell swoop, the Commission created a powerful new structure to ensure that ConEd was examining all of its capital investments through the lens of resilience, established a requirement that ConEd incorporate consideration of future climate risks and impacts into all of its capital investment decisions, and then applied those same standards to every utility in the state of New York. [345]

In other words, it created a regulatory mandate for resilient decarbonization.

The importance of this decision cannot be overstated. In a first for a regulatory body of its scope and powers, the Commission recognized that investments in future electric systems needed to take climate risks and impacts into account, and that the best way to do so was by considering how to maximize the resilience of both existing components of and new additions to the system — preferably in a manner that promoted decarbonized generation. Using the usually-mundane regulatory process of setting rates for electric service, the PSC managed to create a robust process for driving resilient decarbonization.

Gundlach (2020) argues that the ConEd rate case will prove to be an important precedent for those looking to push regulators to impose climate vulnerability assessment requirements on electric utilities. After all, New York is far from unique in facing climate risk. In the years to come, we should expect to see the PSC's 2014 order serve as a template

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[343] New York State Public Service Commission, 62, 67–68.
[344] New York State Public Service Commission, "Order Adopting Storm Hardening and Resiliency Collaborative Phase Three Report Subject to Modifications," 71–72.
[345] Van Nostrand, "Keeping the Lights on during Superstorm Sandy," 123–24.

for other states looking to implement climate risk vulnerability assessment processes, and drive the resilient decarbonization of their electric systems.

While the PSC's order was a massive leap forward for resilient decarbonization efforts, we must concede that regulatory processes (even innovative ones like this) still operate at regulatory speeds — that is, slowly.

During its 2014 rate case, ConEd committed to investing $1 billion in resilience-based storm protection measures, which it dubbed "Fortifying the Future" — a commitment it followed through on by the end of 2017.[346] It also agreed to complete the PSC-mandated vulnerability assessment process by the end of 2019 — which it did, successfully submitting its final assessment in December 2019.[347] With the submission of the assessment, ConEd committed to submitting a Climate Change Implementation Plan by the end of 2020 — which would detail the utility's adaptation governance and strategy with targets for 2025, 2030, and 2040.

It's important to reiterate that ConEd has taken significant steps — totaling in the billions of dollars, in terms of investments — to harden its system and build resilience in the wake of Sandy. However, the fact remains that one of the utilities hardest hit by Hurricane Sandy will not have a comprehensive, overarching strategy for dealing with the impacts that future Sandy-caliber storms might have on its system until the end of 2020— over eight years after the storm surge inundated Lower Manhattan

From this one facet of the PSC-created process, we are offered compelling evidence that regulatory-driven resilience efforts are liable to move at regulatory speed — proceeding through the transparent and deliberative, but (to put it bluntly) plodding processes that public service/utility commissions have established over decades. While we do not contest the value of open public deliberations when it comes to utility regulation, their slow, drawn-out nature — and the decadal time scale of the infrastructure investments they authorize — means that early action is crucial if these regulatory processes are to be useful in driving resilient decarbonization.

The PSC's 2014 order serves both as a guiding example of how existing electric regulatory systems can be used to drive resilient decarbonization, and of the long timescales

[346] Consolidated Edison Company of New York, "Post-Sandy Fortifications Prove Wise $1 Billion Investment For Customers."
[347] Consolidated Edison Company of New York, "Climate Change Vulnerability Study."

that can be involved. However, if we step back and consider what has happened in the wake of the PSC's 2014 order and the NJ BPU's approval of a scaled-down version of Energy Strong, we observe a promising trend.

In New Jersey, PSE&G followed up on the electric system components Energy Strong plan with a four-year, $1.5 billion successor in June 2018. Creatively named Energy Strong II, the plan aimed to continue PSE&G's work to elevate and harden its existing electric infrastructure, while investing further in resilience-oriented system design and technologies.[348] While the proposal was scaled back to $842 million over four years by the BPU before final approval, it is serving as the cornerstone of PSE&G's ambitious decarbonization efforts.[349]

Upon taking office in 2018, Governor Phil Murphy rejoined the Regional Greenhouse Gas Initiative carbon pricing group, and issued an executive order requiring that the next iteration of New Jersey's Energy Master Plan (EMP) be centered around a plan to fully decarbonize the state's electric system by 2050.[350] As the EMP was being developed, PSE&G announced its own Clean Energy Future plan. The plan includes deploying 40,000 electric vehicle chargers across New Jersey, connecting all 2.2 million of its customers to a next-generation control system using smart meters by 2024, making investments in battery storage to help meet the EMP's goal of installing 3 GW by 2030, and implementing a massive energy efficiency program.

The $4.2 billion Clean Energy Future plan is PSE&G's roadmap towards decarbonization — one that the utility proudly notes is built on the foundation laid by its Energy Strong efforts.[351] The utility's initial investments in electric system resilience are now catalyzing a whole series of resilient decarbonization efforts that will shape its future.

Jumping back across the Hudson to New York, we find a similar story unfolding in ConEd's future planning. Like PSE&G's Clean Energy Future, ConEd's Electric Long Range Plan (ELRP) for 2019-2038 is rooted in the state of New York's ambitious climate targets — 40% decarbonization by 2030 and 80% by 2050, economywide, as well as a 50% RPS by 2030. Building on the foundation laid by Fortifying the Future, and following the resilient decarbonization framework laid out in the PSC's 2014 order, ConEd has charted an ambitious

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348 Public Service Electric and Gas Company, "Energy Strong II."
349 Johnson, "PSE&G's Scaled-Back Proposal for Upgrading Gas and Power Grids OK'd."
350 Murphy, "Executive Order 28."
351 Public Service Electric and Gas Company, "Clean Energy Future."

course forward. By 2038, its ELRP seeks to procure an additional 1 GW of solar capacity, install 1.4 GW of battery storage, support an additional 1.1 million electric vehicles, and have demand management and energy efficiency programs in place that equal 20% of its total 2017 electricity sales.[352] Just like PSE&G, ConEd is making the transition from resilience to resilient decarbonization.

The New York/New Jersey region has come a long way since the devastation of Superstorm Sandy nearly eight years ago. The shift towards resilience that began in 2014 with Energy Strong and Fortifying the Future has now turned in to a full-blown resilient decarbonization effort with the Clean Energy Future and the ELRP.

From the eye of a hurricane, a vision of a decarbonized future seems to have emerged and taken on a life of its own.

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[352] Consolidated Edison Company of New York, "Electric Long Range Plan, 2019-2038," 10–14.

# 4 Lessons for resilient decarbonization

Following our examination of three of the most devastating extreme weather events of the past decade, we will now seek to lay out the key, cross-cutting lessons that each offers to inform future resilient decarbonization efforts. We find that these lessons fall into three broad categories: those about the risks we face, those about the role of resilience, and those that encourage us to reimagine our electric systems.

## 4.1 Risk

**Climate risks and impacts aren't black swans**

Being caught off guard by climate-driven extreme weather, as we saw in each of our cases, should no longer be an acceptable outcome for those planning, operating, or overseeing electric systems in the United States. In the coming decades, every resilient decarbonization effort — and, for that matter, every effort to reliably operate an electric system — must be rooted in a careful consideration of the climate risks that the electric system faces, and a plan to deal with the climate impacts it will likely have to contend with.

Our broad review of the National Climate Assessment, the federal government's climate science consensus, revealed that U.S. electric systems face a wide range of growing risks due to climate change — from gradual increases in temperature and sea levels, to increasingly frequent and intense storms and droughts. In forty years of NOAA data, we saw that extreme weather events like Atlantic hurricanes and wildfires make up an overwhelming share of the damage caused in the U.S. by weather and climate-related events — a share that continues to grow rapidly. And we recognized that the massive buildout of infrastructure necessary for electric system decarbonization will almost certainly take place across parts of the U.S. that are already most vulnerable to extreme weather events.

While these trends are concerning, they are widely understood and accepted — and should not come as any surprise to those planning, operating, or overseeing electric systems. Under McCollum, et al.'s taxonomy, these events are "disruptive drivers" and extreme "transient events," not "unexpected outcomes" or "black swans" that fall outside the range of what is widely considered possible.

However, we saw time and time again how utilities and regulators alike failed to recognize the risks that these trends pose to their electric systems in a timely manner. In

Puerto Rico, PREPA and its overseers were stretched to their limit just trying to keep their temperamental system solvent and functional. While they were no strangers to hurricanes, the back-to-back punches of Irma and Maria, coupled with Maria's immense strength, left them operating far beyond any conditions they'd planned for. In California, a long-held belief that the Diablo winds were not as dangerous as the Santa Ana left both PG&E and CPUC scrambling to play catchup as rising temperatures, shifting wind patterns, and an unprecedented drought dramatically increased wildfire risk in Northern California. And in New York and New Jersey, utilities were caught off guard when Hurricane Sandy — fueled by a confluence of meteorological bad luck and rising ocean temperatures — took a left turn towards their region.

In the interest of fairness, we must concede that hindsight and recent research on regional variation offer us a perspective on climate risks and impacts that is far clearer than those that utilities and regulators had at various points over the past decade. But even if we concede these organizations the oversights of the past, there is no reason for them to be repeated.

In each of the three cases we examined, we have seen a commitment to making the consideration of climate risks and impacts a routine part of how electric systems work, from daily operations to multi-decadal resource planning. This is an extremely positive trend, and one that ought to be widely adopted by system operators, and enforced by regulators. While significant uncertainties still surround the precise nature and magnitude of climate risks and impacts, ensuring that they are accounted for at critical stages in electric planning and operations will go a long way towards mitigating them.

**Climate impacts make the bad, worse: loss amplification & compound risks**

Climate risks and impacts don't exist in a vacuum, and they seldom leave affected regions the time to fully recover before striking again. In each of our cases, we saw extreme weather events strike regions already weakened by recent extreme events, or by existing, systemic vulnerabilities. Resilient decarbonization efforts will have to consider how electric systems can withstand not just a Maria, but an Irma followed by a Maria, in a commonwealth already under intense socioeconomic pressure.

Puerto Rico's experience with Irma and Maria exemplifies the challenges of both successive extreme weather events and cross-domain risks. The back-to-back blows inflicted on the island's electric system is a classic case of loss amplification, as the insufficiently resilient system remained weakened after Irma, making it far more vulnerable to the onslaught it received from Maria. At the same, time, we saw how the commonwealth's fiscal and social crises compounded the damage inflicted by the storm. Puerto Rico's electric recovery was heavily impeded both by PREPA's financial constraints, and its lack of institutional capability to handle such a massive undertaking. At the same time, the existing vulnerability of wide swathes of Puerto Rico's population made the impacts of losing power for months even worse, subjecting a population already grappling with nationwide-high poverty levels to an additional level of stress — and likely increasing the death toll, in the process.

In Northern California, the bursts of wildfire-producing Diablo winds built off one another, sending temperatures higher, humidity levels lower, and progressively drying out more and more fuel — each of which progressively increased the risk of catastrophic fires. At the same time, the climate-driven increase in wildfire risk compounded the challenges already posed by PG&E's most antiquated equipment, like the century-old towers on the Caribou-Palermo line that would spark the Camp Fire. Equipment that had long passed its "mean life expectancy" and almost hit its "maximum lifespan" was quite literally pushed to the breaking point by 100 mile per hour winds that added to nearly a century's worth of wear and tear. Even when trying to institute proactive power shutoffs, PG&E was faced with the threat of back-to-back Diablo wind events of record magnitudes.

And in New York and New Jersey, we saw how a meteorological triple-play — a continental low, an offshore high, and an extra-tropical hurricane feeding off record-warm waters — combined to make Superstorm Sandy the destructive event that it was. And even after the storm had passed, a Nor'easter sent many residents who had regained power back into the dark.

While climate risks and existing vulnerabilities were the primary compounding risks and loss amplifiers we observed, it's worth noting that they are far from an exhaustive list — a lesson made clear by the still-unfolding impacts of the COVID-19 pandemic on PG&E's mitigation efforts ahead of the 2020 fire season, and Puerto Rico's recovery from the earthquakes that have rocked it as the pandemic unfolded.

While a *ceteris paribus* approach can be helpful when assessing the drivers of climate risks, or trying to isolate the magnitude of a particular localized impact, it can prove fatal to the kind of high-level, context-aware planning and operations that we argue is necessary for resilient decarbonization. A rigorous examination of climate risks and impacts requires taking into account the potential for compounding and loss amplifying events, from a variety of sources.

One of the key values of a resilience-centric approach to decarbonization is the emphasis on graceful failure modes, which allow electric systems to bend, not break, in the face of repeated extreme events, or ones that compound the challenges of extreme vulnerabilities. PG&E's PSPS efforts in 2019 offered an indication of how resilience can help electric systems gracefully fail and effectively recover in the face of complex extreme events, though it also underscored the difficult choices they can force.

**Legal & financial climate impacts: tipping points & potential opportunity**

Having read just the Foundation section of this thesis, one might be forgiven for thinking that the physical risks and impacts of climate change would be the animating forces of the case studies that followed. However, as we examined in great depth, tipping points — the critical thresholds beyond which an extreme weather event becomes a crisis — can stem from financial and legal risks, as well.

While both the human toll and the physical damage caused by Hurricane Maria and the Northern California wildfires were tragically high, we find that the total impact that these extreme weather events inflicted was greatly exacerbated by the dire financial straits that Puerto Rico found itself in when Maria hit, and the legal liabilities that drove PG&E into bankruptcy.

As we examined through our exploration of Puerto Rico's financial history, the commonwealth's financial misfortunes — from the triple tax exemption and the debt crisis, to the phaseout of Section 936 and the Chapter 9 amendment, to the 2015 debt default — significantly constrained its ability to respond quickly and effectively to the damage wrought by Maria. This includes the blows dealt to PREPA's finances and its work force. From the 2015 debt default, onwards through PROMESA and PREPA's Title III filing, the utility found itself hamstrung by the fiscal constraints imposed on it — constraints that informed everything from its decision to pursue the Whitefish Energy contract, to the structure of the 2019 IRP and the GridMod plan.

PG&E, as we have discovered, is no stranger to Chapter 11 bankruptcy proceedings. But the $30 billion deluge of lawsuits that pushed it to file in January 2019 was a truly novel event. For while the fires undoubtedly damaged both PG&E's equipment and the surrounding areas, it was the threat of the legal and financial consequences that the utility faced as a result — not the physical damages — that actually drove it to seek bankruptcy protection.

From these two events, we see that the legal and financial impacts of extreme weather can be just as devastating as the physical ones.

Hill and Martinez-Diaz make a compelling case that climate risk has been very poorly priced into current financial markets, with a particular focus on equity and bond markets — a potential explanation for PG&E's woes, at least. However, they also highlight that this could be a potential opportunity for organizations looking to mitigate those risks.

They argue that the lack of adequate climate risk pricing in bond markets — particularly municipal bond markets — should make early financing of resilience efforts more profitable, due to exactly the kinds of tipping-point events that Gundlach describes. They argue that eventually, the financial system will have to wise up — whether as the result of an extreme weather even that imposes severe financial liabilities (a la PG&E) or a regulatory mandate (a la ConEd).

In that event, they argue that debt financing for more risky organizations or localities will suddenly become much more expensive/less attractive to investors, while debt financing for organizations or localities that have already made significant progress in building their resilience capacity will be much cheaper and more attractive to investors. This yields two different kinds of financial benefits.

First, there is a first-mover advantage in play — those who are the most resilient/have the most risk mitigation in place at the time of the financial/market "tipping point" will likely stand to benefit from investors' flight away from riskier/less attractive bonds. At the same time, being a first mover could allow those organizations to take advantage of the current information asymmetry — creating a strong incentive for them to finance resilience efforts early, in order to lock in cheaper debt financing.

Taken together, we conclude that the legal and financial impacts of climate risks are quite significant, are insufficiently priced in current financial markets and legal systems, and must be a subject of active consideration for organizations at risk. That said, we also note that the current information asymmetry might open a window, however narrow, for near-term efforts that could both yield first-mover benefits and help finance resilience.

## 4.2 Resilience

**Resilience offers tangible protection against extreme weather**

The cases we consider here support our argument that resilience-based approaches can help protect electric systems against the risks and impacts of climate-driven extreme weather. While resilience measures cannot entirely mitigate the effects of extreme weather (and often come with side effects of their own, as we discovered), they nevertheless are a valuable tool for electric systems under pressure.

We find that resilience measures — combining adequate levels of system hardening with a focus on proactive planning, graceful failures, and effective recoveries — contribute positively to electric systems' ability to endure extreme weather events with a minimal amount of lasting impact.

The lessons of California's 2019 fire season offer the most direct support for the value of resilience in electric systems. PG&E's use of sectionalization technology and proactive power shutoffs allowed it, by the utility's own account, to prevent over 2 million people from losing their power during PSPS events, and avoid the initiation of hundreds of potential wildfires under conditions that matched and exceeded those that sparked the devastating October 2017 wine country blazes.

We concede that the question of whether an average 55 hours of planned blackouts per customer is an acceptable side effect of those gains remains valid. However, the value of resilience goes beyond direct metrics of "crises averted."

While PG&E's technical upgrades and PSPS events were the foci of its 2019 wildfire responses, the billions of dollars it has committed to investing in the wide range of wildfire risk mitigation efforts — from vegetation management to a meteorology team — laid out in its WMP played an important role in keeping the 2019 fire season relatively mild. And the utility's resultant plans to replace or retire some of the oldest parts of its system — like the Caribou-Palermo line— will remove critical vulnerabilities that have proven how dangerous they can be. Going forward, California's $21 billion Wildfire Fund appears likely to provide a substantial buffer for PG&E and its fellow utilities against the growing wildfire risks they face.

As the NCA noted, some of the value of resilience efforts also comes from ensuring that climate and extreme weather risks are appropriately elevated in planning. While

PREPA's 2016 IRP made almost no mention of climate change or extreme weather, its 2019 IRP and the accompanying GridMod plan were designed around MiniGrids and the concept of electric system resilience — a direct response to the events of Hurricane Maria, and the threat of more storms like it to come.

And in New York and New Jersey, a push for resilience in the wake of Superstorm Sandy led to PSE&G's Energy Strong investments, and ConEd's Fortifying the Future push. While intended as responses to the weakness exposed by Sandy, both efforts have become foundational components of their respective utility's long-term plans for their energy systems.

Taken together, we see that resilience-based approaches have not only directly helped reduce the impacts of extreme weather risks, they have also helped make addressing climate risks a key priority of each of the utilities we considered here. Those utilities, in turn, have taken steps to place climate resilience at the core of their future plans for their electric systems — a move that will offer further protection against the growing risks of extreme weather in years to come.

**Climate resilience can enable and catalyze decarbonization efforts**

In addition to examining the role of resilience as way to protect electric systems against the impact of extreme weather, we also find that resilience plays a valuable role in catalyzing decarbonization efforts. As the NCA suggested, efforts to rebuild or restructure electric systems to ensure resilience against extreme weather often open the door to broader efforts to transform them — especially decarbonization. As we've seen, the use of decarbonized generation has factored heavily into resilience-oriented plans for

In Puerto Rico, a post-Maria focus on resilience has completely transformed PREPA's plans for the island's electric system. In 2016, the utility's IRP was largely focused on constructing natural gas plants and expanding the island's LNG transport capacity, with noncommittal, passing mentions of solar power and energy storage systems. In sharp contrast, while PREPA's 2019 IRP still places a heavy emphasis on natural gas, it calls for the installation of 1800 MW of solar generation capacity and 920 MW of battery storage capacity. These ambitious, firm targets were incentivized by the massive push to rebuild and restructure PREPA's transmission and distribution system, including the MiniGrid proposal, which is intended to increase the system's resilience against another Maria-like storm. The billions of dollars that the GridMod plan has promised for transmission and distribution upgrades, as well as control system modernization, all serve to enable increased penetration of low-carbon generation sources like solar power.

It remains to be seen if PREPA can actually meet the ambitious targets it has set forth for solar and battery capacity set out in its 2019 IRP and the GridMod plan, but if it manages to do so, it will meet and exceed its 2025 and 2040 goals for decarbonization — a remarkable feat, considering the extent of the devastation wrought on its electrical system in 2017.

In New York and New Jersey, a similar dynamic appears to be at play, with PSE&G and ConEd's resilience-driven focus on grid modernization serving to complement the ambitious targets for decarbonization that have been set forth by Governors Cuomo and Murphy.

By contrast, the impact of a lack of resilience in Northern California's decarbonization efforts offers a sort of supporting counterexample. In the decades before the Camp Fire, PG&E had been moving at a breakneck pace to decarbonize its system, firmly establishing itself as a leader in renewable generation. At the same time, lawmakers in Sacramento were pushing RPS standards higher and higher, with CPUC taking its lead from them prioritizing an often-disjointed portfolio of climate and clean energy policy issues. While we have established that this was far from the primary driver of the surge in wildfires that the state has experienced over the past decade, we must concede that it played some role, given that it shifted the Commission's focus away from safety and maintenance as climate-driven wildfire risk rose dramatically across Northern California.

Together, the combination of a lack of focus on safety and maintenance, and the lack of timely attention to the growing wildfire risks in Northern California (by both PG&E and CPUC) helped set the stage for the catastrophic fires of the late 2010s. They also set the stage for the crippling legal liabilities which would overwhelm PG&E, forcing it into bankruptcy — and directly jeopardizing the $42 billion it had committed to power purchase agreements supporting new additions of renewable capacity over the coming years.

While a post-crisis focus on resilience has served to help Puerto Rico, New York, and New Jersey accelerate their decarbonization efforts, a lack of resilience put the future of Northern California's nation-leading decarbonization efforts in question.

Taken together, the cases we consider here present compelling evidence that resilience efforts in electric systems play important roles in catalyzing decarbonization efforts, by enabling the expansion of decarbonization ambitions. However, we also note that a lack of resilience in electric systems can actively hinder decarbonization efforts, putting existing progress at risk.

**A crisis wasted? It depends on the crisis, and how prepared you are to act**

One provocative question we asked at the outset of this thesis was whether the recovery from an extreme weather event could act as a catalyst for transformative actions to address broader, structural challenges in electric systems? Could the aftermath of a catastrophic hurricane or wildfire season serve as a "holy-shit moment" as Christina Romer put it, or a "no more moment" in the words of Hill and Martinez-Diaz – potentially one that enables decarbonization?

Based on the cases we examined, we find mixed results. The primary differentiator, however, appears to be variation in the severity of the crisis at hand, and in existing institutional capacity of the organizations seeking to push transformative change.

In the wake of Hurricane Maria, the devastation inflicted upon Puerto Rico provided a powerful incentive for a dramatic overhaul and the island's electric system. For the most part, it appears that PREPA and the commonwealth have done their best to seize the moment, as evidenced by the increased ambition of PREPA's 2019 IRP and the GridMod plan. However, the failure of imagination — the failure to shoot for more ambitious, fossil-fuel-free targets — that EDF criticized can also be chalked up to a lack of institutional capacity. The existing weaknesses in both PREPA's financial position and its electrical system meant that even in the wake of a crisis that was widely agreed to merit a transformative response, PREPA was constrained by its own limited capabilities. Moreover, those same limitations contributed to the severity of the post-Maria outages, which sapped resources that might otherwise have been devoted to even more ambitious decarbonization plans.

New York and New Jersey experienced a similar wakeup call, with the impact of Superstorm Sandy feeling like a second strike after Hurricane Irene struck the region just a year earlier. However, Sandy, while quite destructive, didn't impose an extended paralysis on the region, as Maria did in Puerto Rico. Moreover, the significantly stronger financial positions of the governments and utilities involved, coupled with a much larger shot of federal aid that was delivered much more promptly, gave New York and New Jersey the resources with which to fully embrace the "Rebuild by Design" mentality, and reimagine their electric systems through the lens of resilient decarbonization.

While Puerto Rico and New York/New Jersey all took the aftermath of crises as nudges towards transformative change, California had two very different experiences with the power of crises to shape agendas. Over the course of the past two decades, PG&E experienced crisis-induced priority whiplash, as it sought to balance its decarbonization efforts with the aftermath of the San Bruno explosion, all while the growing risk of wildfires crept towards it. As a result, PG&E's response was to double down on fixing the problems that caused the crisis, and little else — leading it to swing its maintenance spending focus from its electric system to its natural gas system — just as it had focused on boosting earnings after its 2004 emergence from its first bankruptcy.

However, in the wake of the 2017-2018 wildfire seasons and PG&E's bankruptcy, the need for a transformative response had become widely accepted in California, as well. PG&E's aggressive Wildfire Mitigation Plan, coupled with what will likely be a fairly rapid exit from bankruptcy, are both signals that the utility is making an effort to place building resilience in the face of growing wildfire risks at the top of its institutional priorities. Additionally, the swift passage of A.B. 1054 (aided in no small part by the threat of credit rating downgrades for SCE and SDG&E) enabled the creation of the Wildfire Fund, a novel buffer for the inverse condemnation liabilities the utilities will likely continue to face. The creation of the Fund, and the associated restrictions and requirements that A.B. 1054 imposed on the utilities, has fundamentally restructured the legal liability paradigm for wildfire risk in California — all in less than a year and a half since the Camp Fire.

California's experience in the wake of the Camp Fire suggests that a well-resourced state working with utilities who still maintain sizable access to financing can turn the aftermath of a crisis into an opportunity — if not to further decarbonization, then to dramatically reduce one of the most prominent risks it faces. However, PG&E's experience in the wake of San Bruno and its first bankruptcy offer a cautionary note, suggesting that crises can also just lead to a perpetual crisis mentality — leaving no time to address big, structural challenges.

Taken together, these cases suggest that while the aftermath of extreme weather crises can certainly offer "an opportunity to do things that you think you could not before," as Rahm Emmanuel put it, the level of ambition that results depends heavily on the institutional capacity available at the time. And while crises can serve as powerful motivation for transformative change, they can also kick organizations into a "crisis mode," focused on trying to address the mistakes of the last crisis, with little room for forward-looking ambition.

**Harness existing regulatory processes, but do it early**

Existing regulatory channels can serve as powerful fora for promoting resilient decarbonization, but they are prone to moving at regulatory speed — which is to say, slowly. While this might not ordinarily be a problem, the cases we examined have shown that given current and projected climate trends, the pace of extreme weather can quickly exceed regulatory progress. As a result, efforts to promote resilience decarbonization though existing regulatory channels need to start as early as possible, to counteract the inevitable lag in the processes.

Puerto Rico's IRP process has been a remarkable forum for subjecting PREPA and the island's electric system to rigorous, transparent scrutiny — scrutiny that directly contributed to PREB's push for PREPA to lean further into its decarbonization commitments with a second version of the 2019 IRP. However, the timeline of this IRP also serves to illustrate the rate at which extreme weather events can overtake regulatory proceedings. The IRP was originally scheduled for submission in 2018, but had to be delayed because the events of Hurricanes Irma and Maria completely altered Puerto Rico's electric system. While PREPA finally managed to submit a fully fleshed-out IRP for PREB's consideration by June 2019, earthquakes destroyed Costa Sur — one of the island's largest generators — just six months later, transforming Puerto Rico's electricity landscape once more.

In California, CPUC's oversight of PG&E's wildfire risk mitigation, though delayed, has pushed the utility to step up its efforts to build systemwide resilience — and the safety certification process set out as part of the Wildfire Fund is likely to further that influence. However, CPUC's track record overseeing PG&E remains decidedly mixed. After all, while it was conducting its over four-year-long investigation of PG&E's safety practices, the 2017, 2018, and 2019 wildfire seasons all came and passed — and PG&E itself went bankrupt.

Similarly, while the New York State PSC set a national precedent for using regulatory proceedings to ensure that utilities are operating with resilient decarbonization as their primary focus, the fact remains that its climate resilience orders in ConEd's 2014 rate case will not produce a finalized Implementation Plan until later this year — eight years after Sandy's storm surge inundated Lower Manhattan.

The cases at hand lead us to the simple fact that nature does not operate on regulatory timeline., While regulatory proceedings like IRP processes and rate cases can be valuable tools for driving resilient decarbonization, the reality of extreme weather that power systems are already facing will continue to intrude upon, disrupt, and slow those processes.

This underscores the need to build resilient decarbonization principles, like climate risk assessment, into the core of regulatory review processes, such as IRPS and rate cases, at the earliest opportunity. Doing so will give both the ratepaying public and regulators confidence that when Utility X claims that its new transmission line is adequately protected in light of the expected wildfire risk in the area over its lifetime, or that a new substation is sufficiently elevated to withstand a 100-year storm surge, those claims are based on timely assessments that accurately factor in current and future climate risks and impacts.

**Resilience is a buzzword, but its most important elements aren't**

Ever since Superstorm Sandy made landfall in 2012, "resilience" has become a buzzword in the electric power industry — conjuring up images of sensor networks powered by machine learning preemptively identifying imminent system failures, and providing operators with real-time updates on powerline status using infrared and laser imagery from UAVs. While all of these technologies exist, and will likely play useful roles in the overall effort to increase the resilience of electric systems, the cases at hand reveal that in practice, resilience is far less sexy — but far more impactful.

PREPA's plan to split Puerto Rico's electric system into eight isolatable "MiniGrids," powered by distributed generation is quite ambitious — but it won't get very far unless the utility is able to start making the investments in workforce training and retention, and maintenance, that it has deeply neglected over the past several years.

While we've already discussed the important role that sectionalization technology has played in increasing the resilience of PG&E's electric system, the fact remains that the larger portion of its investments are focused (rightly so) on enhanced vegetation management (tree trimming), emergency inspections (manually examining equipment), ensuring that the equipment it already has is properly maintained, and replacing the equipment that — by its own admission — is too old to still reasonably be in operation.

Similarly, the primary focus of ConEd's resilience efforts has been raising equipment so that even Sandy-level storm surges can't reach it — critical, but not particularly flashy.

Speaking of "not flashy," at the end of the day, the use of more accurate, digitized recordkeeping systems for maintenance operations might end up being the biggest steps towards resilience for both PREPA and PG&E.

As both of their histories remind us, utilities often skimp on relatively "boring" efforts like basic maintenance or recordkeeping when under stress. But as we have seen, these foundational efforts play a critical role in building resilience.

**Resilience is not a silver bullet for inequality**

Throughout this thesis, we have sought lessons for resilient decarbonization from Puerto Rico, California, New York, and New Jersey. However, as the puzzle goes, one of these states is not the same — it's not even a state. Based on the cases at hand, we must point out that while resilience can help alleviate the disproportionate impacts of climate change and extreme weather, it likely cannot serve as a silver bullet for the underlying inequality.

It is likely not lost on the reader that restoring power to 95% of customers took roughly 7 days in New York and 10 days in New Jersey, after Superstorm Sandy in 2012; 14 days in the hardest-hit parts of Houston, after Hurricane Harvey in 2017… and 189 days — over half a year — in Puerto Rico, after Hurricane Maria, that same year.

We have considered a number of factors that may have contributed to these discrepancies. Some are quite obvious: a near-Category 5 hurricane travelling the diagonal of an island that's just 100 miles wide will naturally inflict more damage than a Category 1 extra-tropical hurricane that made landfall more than 100 miles south of the region's major metropolitan area.

Some appear quite obvious (like Puerto Rico's isolation from the U.S. mainland), but have elements that go deeper (like the Jones Act). Others are simple arithmetic: California has 55 Senators and Representatives to advocate on its behalf in Congress, Texas has 38, New York has 29, New Jersey has 14… and Puerto Rico has a single resident commissioner in the House of Representatives, who cannot vote. California, Texas, and New York have the top three largest state economies in the country, New Jersey the 8$^{th}$ largest… and Puerto Rico the 39$^{th}$.

We've also considered more concerning factors, including the relatively slow (and rhetorically combative) federal response to Hurricane Maria, as well as Puerto Rico's endemic challenges with corruption, as exemplified by the Whitefish Energy debacle and the fall of the Rosselló government.

Even if we set aside the precise cause of the discrepancy, we must still contend with its magnitude. Superstorm Sandy and Hurricane Harvey together claimed 224 American lives by the time they dissipated. Hurricane Maria, on the other hand, claimed an estimated 13 times more — 2,975 American lives — with the overwhelming majority of those deaths coming months after the storm passed. And even today, more than two years later, we are still forced to rely on estimates based on excess mortality calculations to assess Maria's impact, because we still don't accurately know exactly how many U.S. citizens died after the storm struck Puerto Rico, or exactly what precipitated their deaths.

The inequality goes beyond just borders, though, Recall that at the peak of the post-Maria "excess mortality" event, nearly 40% more Puerto Ricans were being reported dead from the bottom third of the socioeconomic spectrum, than from the top third.

These statistics lead us to a largely unsurprising, yet still sobering, conclusion: those populations who are already most vulnerable will be subject to the worst impacts of extreme weather. When it comes to electric systems, resilience-based efforts can help buffer the worst of those impacts — employing system hardening, proactive planning, graceful failures, and effective recoveries to minimize the damage inflicted on the most vulnerable communities. And, as we've previously noted, resilience can act as a catalyst for transformative change, including decarbonization.

But at the end of the day, resilience is not a silver bullet for inequality: it is, at best, an arrow in the quiver.

**Stopgap measures will likely play a role, but lock-in is a concern**

Stop-gap measures, which act as a bridge between existing electric systems and ones that are designed with resilience explicitly in mind, will likely play a part in any resilient decarbonization effort.

Many of these stop-gap measures have negative externalities — whether in the form of $CO_2$ emissions or planned power shutoffs — that are acceptable for the moment (especially when compared to the impacts of extreme weather that they mitigate), but are incompatible with the long-term goals of resilient decarbonization.

Caution must be given to ensure that investment in these kinds of stop-gap measures doesn't lead to lock-in beyond the desired use or timeframe.

Puerto Rico's growing appetite for natural gas, both in the form of 302 MW CCGTs and 24 MW peakers, appears to be an improvement over its current reliance on aging heavy fuel oil-fired plants and peakers — both in terms of resilience and progress towards decarbonization. However, the fact remains that $CO_2$-emitting generation sources, including natural gas, are ultimately incompatible with the long-term goal of decarbonization. But in the face of the nearly $1.5 billion that PREPA has proposed investing in CCGTs, peakers, and an LNG terminal, it is worth asking whether the utility is making investments with an eye towards short-term resilience that could compromise its long-term decarbonization goals, and potentially leave it with stranded assets on its hands.

Meanwhile in California, PG&E experienced a far less damaging wildfire season in 2019, than in 2017 and 2018, due in no small part to its use of Public Safety Power Shutoffs. These preemptive shutoffs, taken as a last-resort in the face of extremely dangerous weather conditions, appear to have helped PG&E gracefully fail its system — as opposed to risking the ignition of wildfires. However, leaving millions of Californians in the dark for days on end is — as PG&E itself admits — not a sustainable practice in the long run.

PREPA and PG&E's experiences with stopgap measures affirm our contention that while stopgaps can be quite useful in the near-term, they must be carefully implemented with consideration given to the risk of becoming overly reliant on them in the long term.

## 4.3 Reimagining

**Ambitiously questioning the status quo can catalyze tangible progress**

The bulk of this thesis has examined the case for building resilience to climate-driven extreme weather risks within existing institutional structures, as a means to both protect and catalyze the decarbonization of the U.S. electric power system.

However, in the course of our cases, we have encountered a number of more radical proposals that question the status quo of how electric systems are structured. We find that these proposals, though not all enacted, were each able to catalyze progress on key aspects of resilient decarbonization by creating a narrative of what progress ought to look like, and then forcing existing institutions to counter that narrative.

In California, a chorus of public officials ranging from the Mayors of San Francisco and San Jose, to Governor Newsom, have suggested at various points during PG&E's bankruptcy proceedings that the utility's current structure contributed to its role in starting wildfires. Proposals ranged from individual cities seeking to buy out the PG&E owned transmission, distribution, and generation assets serving them and form municipal utilities, to Newsom's repeated threat that if PG&E didn't present a bankruptcy plan that sufficiently protected the interests of the public, the State of California would consider taking over the utility. While none of these will come to pass, it appears that each of these proposals have helped shape both PG&E's bankruptcy proceedings and its response to its past and future wildfire risks and liabilities. The municipalities were part of a $1 billion settlement with PG&E, while Newsom was able to secure several key concessions in exchange for his support of the utility's ultimate reorganization proposal.

In the wake of Superstorm Sandy, Governor Andrew Cuomo — joining a chorus of elected officials and public advocates — argued that LIPA's electric system ought to be placed under new operational management, following its poor performance during and in the aftermath of the storm. When LIPA and its then-operator, National Grid, failed to offer a compelling alternative, day to day operations of LIPA's system was given under contract to PSE&G. Similar proposals have been made for privatizing the operations of PREPA's system.

Beyond reconsidering the corporate structure and operations of electric utilities, some have called for reexaminations of their natural monopolies — with one proposal calling for a review of PG&E's Northern California electricity franchise every 25 years.

While none of these proposals, save the LIPA handover, were ultimately implemented, they serve as valuable reminders of the value that seemingly simplistic questioning of fundamental conditions of the status quo can have, by driving tangible progress in existing electric institutions.

**Public vs. private incentives for electric systems**

Across our cases, we've seen how short-term financial incentives can distort the behavior of utilities: causing them to hop priorities from increasing earning, to cutting rates, to minimizing liabilities, and beyond. These short-term incentives often find themselves in conflict with longer-term public goals such as safety, maintenance, resilience, and decarbonization efforts. At a time when our society depends on electricity as a background or baseline input for nearly all of our personal needs and economic activity, it is worth taking a moment in our exploration of resilient decarbonization to consider what role electricity itself should hold.

Going beyond the details of risk, resilience, and decarbonization that are the focus of this thesis, we identify a fundamental question that our examination of resilient decarbonization and the cases at hand raises: in today's society, how should electric systems balance near-term financial and market incentives with longer-term, public goals?

California's legal doctrine already treats electric utilities like PG&E as "more like a government entity than a private employer" — subjecting it to the same standards of inverse condemnation liability as the government, and only allowing it to operate in close coordination with CPUC. However, at the same time, PG&E remains a publicly traded, investor-owned, for-profit utility — an organization whose basic role is to provide electricity and natural gas to 16 million Californians, in order to generate revenue and earn returns for its shareholders. Over the course of our analysis of PG&E here, we have identified numerous instances where the company's short-term financial and market incentives diverged from longer-term public goals — often leading to disasters.

However, this is not to say that investor-owned-utilities are the only ones facing these challenges. After all, PREPA — a government-owned corporation — has experience many of the same challenges that PG&E has focused. However, in PREPA's case, these challenges have stemmed not from shareholder pressures but from political ones, largely driven by fiscal constraints.

Nor are these challenges limited to the utilities themselves. Across our cases, we've seen a number of prominent financial and consulting firms face accusations of placing financial interests over broader public interests. In Puerto Rico, UBS faces accusations that it improperly profited off the commonwealth's financial crisis, while McKinsey is also accused of aligned restructuring efforts to favor of bondholders. Additionally, we saw the EDF raise concerns that Siemens — a leading producer of natural gas turbines — was using its preparation of PREPA's IRP to steer Puerto Rico towards a natural gas-dependent future. And in California, PG&E spent $270 million on an Accenture contract that led it to outsource key safety and maintenance functions to save short term costs, contributing to far greater long-term challenges.

The mission of the Federal Energy Regulatory Commission, which oversees the U.S. bulk power system, is to ensure "Economically Efficient, Safe, Reliable, and Secure Energy for Consumers" — a goal that seems to thread the needle between short-term financial incentives and long-term public goals. Volumes have been written about the theoretical, empirical, and practical methods that can be employed to internalize externalities, address failures, and realign incentives in open markets. However, in practice, we've seen that financial constraints regularly still manage to come between the two.

On one hand, the ripple effects of financial pressures and debt securitization appear to have played a significant role in exacerbating the post-Maria crisis in Puerto Rico — a crisis that was already brewing before the storm hit.

However, we must also consider the fact that the financial liabilities faced by PG&E's shareholders in the aftermath of the Camp Fire, and the utility's subsequent bankruptcy, appear to have led to a newfound prioritization of safety, maintenance, and building resilience in the face of growing climate risks. A key component of this transformation has been the creation of the Wildfire Fund, which is essentially a distributed buffer for the utilities against wildfire liabilities.

Herein, perhaps lies part of the tension: from Puerto Rico's debt restructuring, to PG&E's bankruptcy, to the Wildfire Fund itself, the primary focus of each effort appears to be devoted to ensuring that the financial viability of institutions is preserved — with the impact on the people the electric system exists to serve as an ancillary input to that priority. As CPUC noted when it approved its regulations implemented A.B. 1054, though the legislation left much to be desired for the public, it was preferable to credit downgrades for the utilities that might leave them without access to the capital needed to finance their operations.

While our cases do not offer an answer to this question, we submit that it is worth further considering whether there are alternate models for providing electric power, more insulated from the tug of market-driven, short-term financial constraints, which might prove better suited to the public goal of resilient decarbonization for U.S. electric systems.

# 5 Conclusion

In this thesis, we have explored the valuable role that resilience-based measures can play by enabling the decarbonization of the U.S. electric system, in the face of the escalating risks and impacts of climate-driven extreme weather.

Starting from a foundation rooted in the need for decarbonizing the electric system, the growing risks and impacts that climate change will have on the U.S., and the role of resilience in electric systems, we built up the concept of resilient decarbonization.

We then proceeded to look back over the past decade, to see what lessons we could glean from three of the most devastating extreme weather events on record.

In the wake of Hurricane Maria, we saw how a financially crippled utility and government lacked the capacity to recover effectively from an unprecedent level of devastation wrought upon Puerto Rico's electric system — and noted that it was the most socioeconomically vulnerable parts of the population that bore the brunt of the loss of life that resulted. However, we also examined the remarkable realignment that PREPA and the commonwealth have made in the years since, centering their entire electric planning philosophy on the concept of resilient decarbonization, by pushing for grid isolation capabilities that can also enable the deployment of more solar generation and battery storage. But in the wake of a series of earthquakes that have struck the island this year, we note that Puerto Rico's plans still have a long way to go.

In Northern California, we confronted PG&E: a utility so busy trying to juggle its past missteps and its future decarbonization efforts, that it allowed the presently growing risk of extreme, climate-driven wildfires to catch it unawares — as did its regulator, CPUC. We examined the decades-long chain of priority whiplash that led both organizations to neglect safety and maintenance, leading to the most devastating wildfire seasons California has ever seen. In the aftermath of the Camp Fire, we saw how building legal liabilities under California's unique doctrine of inverse condemnation sent PG&E into bankruptcy — placing billions of dollars of renewable power purchase agreements at risk. But from there on out, we noted a profound change in orientation. As it seeks to emerge from bankruptcy, PG&E has thrown itself headfirst into its Wildfire Mitigation Plan and system resilience efforts. And the state government created the Wildfire Fund, a novel financial mechanism designed to shield utilities from the runaway liabilities that brought PG&E to its knees, while still trying to maintain some modicum of accountability. In the aftermath of the relatively mild 2019 fire season, aided by PG&E's Public Safety Power Shutoffs, we found that while the utility met the test of resilience on a technical level, plunging millions of Californians into the dark, in order to avoid burning down large parts of the state, can hardly be considered true resilience.

And in New York and New Jersey, we saw a Superstorm that took the nation's largest metropolitan area by surprise transform into a remarkable catalyst for resilient decarbonization. We observed how basic storm hardening measures proposed in ordinary rate cases morphed into full-fledged resilience programs, and marveled at the first-of-a-kind order issued by the New York PSC, which turned the old-fashioned ratemaking process into a regulatory force for resilient decarbonization. And we saw how those investments in resilience have become the foundation of a whole new generation of multi-decadal plans for resilient decarbonization.

Looking across all three of these cases, we identified three major categories of lessons for resilient decarbonization: those about the risks we face, those about the role of resilience, and those that encourage us to reimagine our electric systems.

We noted that climate risks and impacts can no longer be ignored, as they exacerbate a whole multitude of existing vulnerabilities by amplifying extreme weather events. We also examined the legal and financial risks of climate change, both as tipping points to be wary of, and as opportunities to exploit an information asymmetry in support of resilient decarbonization.

Turning to the role of resilience in electric systems, we found that it not only offers tangible protection against the growing risks of climate-driven extreme weather, but also serves to enable and catalyze decarbonization efforts. We found that crises like devastating hurricanes and wildfires can serve as powerful vehicles for transformative change if there is sufficient institutional capacity present, but can prove overwhelming in its absence. While resilience may be a buzzword, we found that its components decidedly aren't, and that neglect of essential functions like maintenance and safety led to many of the crises we examined. Admitting that resilience is far from a silver bullet for the inequities this research has highlighted, we nevertheless contend that resilience can help cushion the blows of extreme weather events for those communities and populations that are already the most vulnerable to them. And while we accepted stopgap measures as a necessary tool, we cautioned to be wary of becoming locked-in.

Finally, we took a step back, and noted that in many cases, proposing radical, likely unrealistic proposals that challenges the status quo of an electric system can help jolt a stagnant bureaucracy or a stalled conversation, helping enable tangible progress towards resilient decarbonization. And we questioned the incentives that drive the generation, transmission, distribution, and sale of electricity — this commodity upon which our lives so firmly depend in this day and age — and considered that short-term financial drives might be crowding out long-term public goals.

Writing this thesis in isolation during the midst of a global pandemic has left me acutely aware of the fragility of so many of the systems — including the electric ones — that power our society, and our lives. But this research has also reaffirmed my faith that even amidst the most charred ashes, and the most scouring winds, we still have the power to regain our footing, and chart a more resilient path forward — one that will allow us to meet the future head on, no matter what it may bring.

## Bibliography


A.B. 1054 - Public utilities: wildfires and employee protection, California Public Utilities Code § (2019). https://perma.cc/7R24-5SUA.

Abatzoglou, John T., and A. Park Williams. "Impact of Anthropogenic Climate Change on Wildfire across Western US Forests." *Proceedings of the National Academy of Sciences* 113, no. 42 (October 18, 2016): 11770–75. https://doi.org/10.1073/pnas.1607171113.

Acevedo, Nicole, and The Associated Press. "5.4-Magnitude Earthquake Hits near Puerto Rico." *NBC News*, May 2, 2020. https://perma.cc/H4XS-U7ZR.

Ailworth, Katherine Blunt and Erin. "PG&E Reaches $1 Billion Settlement With Paradise, California Governments." *Wall Street Journal*, June 18, 2019, sec. Business. https://perma.cc/6XVC-PK4V.

American Public Power Association. "Public Power: 2018 Statistical Report," 2018. https://perma.cc/HJZ9-JEHY.

Article I, §19, California Constitution §. Accessed April 26, 2020. https://perma.cc/AUU5-NUDR.

Avishai, Bernard. "The Pandemic Isn't a Black Swan but a Portent of a More Fragile Global System." *The New Yorker*, April 21, 2020. https://perma.cc/E3HN-3SYX.

Baker, David R. "PG&E Could Put Power Lines Underground, But It's Very Expensive." *Bloomberg*, January 29, 2019. https://perma.cc/8NY4-PA9K.

Bankruptcy Amendments and Federal Judgeship Act of 1983, Pub. L. No. H.R. 5174 (1984). https://perma.cc/9Y7B-ZJ2T.

Barron, Jesse. "The Curious Case of Aurelius Capital v. Puerto Rico." *The New York Times*, November 26, 2019, sec. Magazine. https://perma.cc/SS74-42E9.

Blake, Eric S., Todd B. Kimberlain, Robert J. Berg, John P. Cangialosi, John L. Beven II, and National Hurricane Center. "Tropical Cyclone Report: Hurricane Sandy." National Oceanic and Atmospheric Administration, February 12, 2013. https://perma.cc/J7GJ-F499.

Bloom, Aaron, and National Renewable Energy Laboratory. "Interconnections Seam Study." Presented at the Transgrid-X 2030 Symposium, July 26, 2018. https://perma.cc/6GQ4-DLJP.

Blum, Andrew. *The Weather Machine: A Journey Inside the Forecast*. Ecco, 2019.

Blunt, Katherine. "PG&E Reaches Deal With California Governor on Bankruptcy Exit." *Wall Street Journal*, March 22, 2020, sec. Business. https://perma.cc/X2C2-32PQ.

———. "PG&E to Plead Guilty to Involuntary Manslaughter Charges in Deadly California Wildfire." *Wall Street Journal*, March 23, 2020, sec. Business. https://perma.cc/2BRH-LVHB.

Blunt, Katherine, and Russell Gold. "PG&E Delayed Safety Work on Power Line That Is Prime Suspect in California Wildfire." *Wall Street Journal*, February 27, 2019, sec. Business. https://perma.cc/4B8L-7TKS.

———. "'Safety Is Not a Glamorous Thing': How PG&E Regulators Failed to Stop Wildfire Crisis." *Wall Street Journal*, December 8, 2019, sec. US. https://perma.cc/7VL8-YD9Q.

Blunt, Katherine, Russell Gold, and Rebecca Smith. "PG&E: Wired to Fail." *Wall Street Journal*, December 28, 2019, sec. Business. https://perma.cc/C8LT-HC7T.

Booker, Brakkton. "After Quakes, Puerto Rico's Electricity Is Back On For Most, But Uncertainty Remains." *NPR*, January 13, 2020. https://perma.cc/8PRS-AMZC.

Brady, Jeff. "Climate Change Push Fuels Split On Coronavirus Stimulus." *NPR*, March 24, 2020. https://perma.cc/D2P9-33GX.

California Department of Forestry and Fire Protection. "2017 Fire Season." Accessed May 8, 2020. https://perma.cc/383M-GYQB.

———. "2018 Fire Season." Accessed May 8, 2020. https://perma.cc/8Z6S-5Y6G.

———. "2019 Fire Season." Accessed May 10, 2020. https://perma.cc/23DZ-YJ5X.

———. "CAL FIRE Investigators Determine Cause of the Camp Fire," May 15, 2019. https://perma.cc/BJ7H-5FAX.

———. "CAL FIRE Investigators Determine Causes of 12 Wildfires in Mendocino, Humboldt, Butte, Sonoma, Lake, and Napa Counties," June 8, 2018. https://perma.cc/Q4XK-3U6E.

———. "CAL FIRE Investigators Determine the Cause of the Cascade Fire," October 9, 2018. https://perma.cc/SH7C-E4DN.

———. "Top 20 Largest California Wildfires," August 8, 2019.

———. "Top 20 Most Destructive California Wildfires," August 8, 2019. https://perma.cc/X6LJ-F8UT.

California Independent System Operator. "Final California ISO Transmission Plan, 2010," April 7, 2010. https://perma.cc/T934-64ND.

California Public Utilities Commission. "CPUC Wildfire Safety Division Recommends Approving Utility 2020 Wildfire Mitigation Plans with Conditions," May 7, 2020, 2. https://perma.cc/E836-CGL2.

———. "Decision 12-01-032: Adopting Regulations to Reduce Fire Hazards Associated with Overhead Power Lines and Communication Facilities," January 12, 2012. https://perma.cc/Z262-ANA8.

———. "Decision 19-10-056: Approving Imposition of a Non-Bypassable Charge to Support California's Wildfire Fund and Adopting Rate Agreement Between the California Department of Water Resources and the California Public Utilities Commission," October 24, 2019. https://perma.cc/BY53-CQNX.

———. “Decision Denying Application of San Diego Gas & Electric Company (U902E) for Authorization to Recover Costs Related to the 2007 Southern California Wildfires Recorded in the Wildfire Expense Memorandum Account (WEMA).,” November 30, 2017. https://perma.cc/Y9SW-FV2Q.

———. “Incident Investigation Report for 2018 Camp Fire,” November 8, 2019. https://perma.cc/V344-VL8H.

———. “Initial Safety Certification for Pacific Gas and Electric Company,” August 23, 2019. https://perma.cc/6QXF-NQSK.

———. “Initial Safety Certification for San Diego Gas and Electric,” July 26, 2019. https://perma.cc/WSF8-3VMF.

———. “Initial Safety Certification for Southern California Edison Company,” July 25, 2019. https://perma.cc/V5BS-XAKC.

———. “Resolution WSD-003: Ratifying Action of the Wildfire Safety Division on Pacific Gas and Electric Company’s 2020 Wildfire Mitigation Plan Pursuant to Public Utilities Code Section 8386,” May 7, 2020. https://perma.cc/DB6W-Y59B.

California State Association of Counties. “Inverse Condemnation and Utility Liability,” July 25, 2018. https://perma.cc/3GPK-WRF4.

Campbell, Alexia Fernández. “It Took 11 Months to Restore Power to Puerto Rico after Hurricane Maria. A Similar Crisis Could Happen Again.” *Vox*, August 15, 2018. https://perma.cc/9QZU-R8W3.

Campo-Flores, Arian. “Puerto Rico’s Power Restoration Slowed by Miles of Downed Lines.” *Wall Street Journal*, October 6, 2017, sec. US. https://perma.cc/9YFR-E8FX.

Canepari, Zachary, and Drea Cooper. *Fire in Paradise*. Documentary. Netflix, 2019. https://perma.cc/5NLJ-DMEA.

Center for Corporate Climate Leadership. “Emission Factors for Greenhouse Gas Inventories.” U.S. Environmental Protection Agency, March 9, 2018. https://perma.cc/55U9-8SPH.

Center for Emergency Management and Homeland Security. “Spatial Hazard Events and Losses Database for the United States (SHELDUS).” Arizona State University, December 17, 2019. https://perma.cc/7TM4-4L76.

Chappell, Bill, and Colin Dwyer. “Puerto Rico Declares State Of Emergency After Quake Rocks Residents Awake.” *NPR*, January 7, 2020. https://perma.cc/V8XL-NB9N.

Cheng, Lijing, John Abraham, Jiang Zhu, Kevin E. Trenberth, John Fasullo, Tim Boyer, Ricardo Locarnini, et al. “Record-Setting Ocean Warmth Continued in 2019.” *Advances in Atmospheric Sciences* 37, no. 2 (February 1, 2020): 137–42. https://doi.org/10.1007/s00376-020-9283-7.

Chester, Mikhail V., B. Shane Underwood, and Constantine Samaras. “Keeping Infrastructure Reliable under Climate Uncertainty.” *Nature Climate Change*, April 13, 2020, 1–3. https://doi.org/10.1038/s41558-020-0741-0.

Consolidated Edison Company of New York. “2013 Electric, Gas and Steam Rate Filing.” New York Public Service Commission, January 25, 2013. https://perma.cc/AW5F-YPJY.

———. “Climate Change Vulnerability Study,” December 2019. https://perma.cc/6N2X-S78S.

———. “Electric Long Range Plan, 2019-2038,” January 2019. https://perma.cc/7XGW-SRF2.

———. “Post-Sandy Fortifications Prove Wise $1 Billion Investment For Customers,” October 19, 2017. https://perma.cc/VU29-TNNP.

CPUC Independent Review Panel. “Report of the Independent Review Panel: San Bruno Explosion.” California Public Utilities Commission, June 8, 2011. https://perma.cc/P8F6-FQT4.

Death Cab for Cutie. *Grapevine Fires*. Narrow Stairs. Atlantic Records, 2008. https://perma.cc/FX9D-N63Y.

Deibert, M. *When the Sky Fell: Hurricane Maria and the United States in Puerto Rico*. Apollo Publishers, 2019.

Disaster Relief Appropriations Act, 2013, Pub. L. No. 113–2, U.S.C. (2013). https://perma.cc/S9MP-9KV3.

Eastwood, Rebecca Smith. “PG&E Penalties and Settlements Through the Years.” *Wall Street Journal*, September 5, 2019, sec. US. https://perma.cc/5X2R-L7JJ.

———. “PG&E’s Long Record of Run-Ins With Regulators: A ‘Cat and Mouse Game.’” *Wall Street Journal*, September 5, 2019, sec. US. https://perma.cc/7RSH-D8KK.

“Extremes Makeover.” *Nature Energy* 5, no. 2 (February 2020): 93–93. https://doi.org/10.1038/s41560-020-0572-2.

Fadulu, Lola, and Mark Walker. “Trump Attaches Severe Restrictions to Puerto Rico’s Long-Delayed Disaster Aid.” *The New York Times*, January 15, 2020, sec. U.S. https://perma.cc/4XP6-XS56.

Fagan, Kevin. “PG&E Launches Huge Paper Chase for Pipeline Data.” *SFGate*, March 5, 2011. https://perma.cc/98V3-KXUX.

Feliciano, Zadia, and Andrew Green. “US Multinationals in Puerto Rico and the Repeal of Section 936 Tax Exemption for U.S. Corporations.” Cambridge, MA: National Bureau of Economic Research, August 2017. https://doi.org/10.3386/w23681.

Fisher, Jeremy I, and Ariel I Horowitz. “Expert Report: State of PREPA’s System.” Synapse Energy Associates, November 23, 2016. https://perma.cc/4FZR-CL4M.

Gallucci, Maria. “Puerto Rico Goes Dark (Again) as Earthquakes Rattle Island - IEEE Spectrum.” *IEEE Spectrum*, January 10, 2020. https://perma.cc/WTD5-6WEJ.

———. “Rebuilding Puerto Rico’s Power Grid: The Inside Story.” *IEEE Spectrum*, March 12, 2018. https://perma.cc/HZ3V-KQ5M.

Giel, Dawn. "Ex-UBS Broker Sentenced in Fraudulent Puerto Rico Bond Sales Scheme." *CNBC*, March 26, 2019, sec. Finance. https://perma.cc/AS8H-YJSR.

Gold, Russell. *The Boom: How Fracking Ignited the American Energy Revolution and Changed the World*. Simon & Schuster, 2014.

Gold, Russell, and Katherine Blunt. "PG&E's Radical Plan to Prevent Wildfires: Shut Down the Power Grid." *Wall Street Journal*, April 27, 2019, sec. Business. https://perma.cc/29ZK-2GF2.

———. "This Old Metal Hook Could Determine Whether PG&E Committed a Crime." *Wall Street Journal*, March 8, 2020, sec. Business. https://perma.cc/45QL-ZC6K.

Gold, Russell, Katherine Blunt, and Rebecca Smith. "PG&E Sparked at Least 1,500 California Fires. Now the Utility Faces Collapse." *Wall Street Journal*, January 13, 2019, sec. Business. https://perma.cc/35UE-WEBQ.

Gold, Russell, and Peg Brickley. "PG&E Reaches $11 Billion Settlement with Insurers over Deadly Wildfires." *Wall Street Journal*, September 13, 2019, sec. Business. https://perma.cc/4PQL-L3MF.

Goss, Michael, Daniel L. Swain, John T. Abatzoglou, Ali Sarhadi, Crystal Kolden, A. Park Williams, and Noah S. Diffenbaugh. "Climate Change Is Increasing the Risk of Extreme Autumn Wildfire Conditions across California." *Environmental Research Letters*, 2020. https://doi.org/10.1088/1748-9326/ab83a7.

Goss, Michael, Daniel L. Swain, and Noah S. Diffenbaugh. "Observed Changes in Measures Associated with Wildfire Risk in California." *AGU Fall Meeting Abstracts* 23 (December 1, 2018). https://perma.cc/BR8M-KRJH.

Governor's Strike Force. "Wildfires and Climate Change: California's Energy Future." Office of the Governor of California, April 12, 2019. https://perma.cc/56UG-A5AH.

Graham, David A. "Trump Takes to Twitter as Puerto Rico's Crisis Mounts." *The Atlantic*, October 1, 2017, sec. Politics. https://perma.cc/5AVU-TQCT.

Greenberg, Jon. "Mystery: Strom Thurmond, Puerto Rico and Bankruptcy Protection." *PolitiFact*, April 26, 2016. https://perma.cc/MD9M-8KFX.

Greenberg, Scott, and Gavin Ekins. "Tax Policy Helped Create Puerto Rico's Fiscal Crisis." *Tax Foundation* (blog), June 30, 2015. https://perma.cc/9RPS-LXDU.

Griffin, Paul A. "Energy Finance Must Account for Extreme Weather Risk." *Nature Energy* 5, no. 2 (February 2020): 98–100. https://doi.org/10.1038/s41560-020-0548-2.

Grotzinger, J., T.H. Jordan, F. Press, and R. Siever. *Understanding Earth*. 7th ed. W. H. Freeman, 2009.

Grunwald, Michael. *The New New Deal: The Hidden Story of Change in the Obama Era*. Simon and Schuster, 2012.

Gundlach, Justin. "Climate Risks Are Becoming Legal Liabilities for the Energy Sector." *Nature Energy* 5, no. 2 (February 2020): 94–97. https://doi.org/10.1038/s41560-019-0540-x.

Haley, Ben, Ryan Jones, Gabe Kwok, Jeremy Hargreaves, Jamil Farbes, and James H. Williams. "350 PPM Pathways for the United States." U.S. Deep Decarbonization Pathways Project, May 8, 2019. https://perma.cc/83LV-ASFQ.

Hill, Alice C., and Leonardo Martinez-Diaz. *Building a Resilient Tomorrow: How to Prepare for the Coming Climate Disruption*. Oxford University Press, Incorporated, 2019.

Hinds, Kate. "Totaling Sandy Losses: How New York's MTA Got to $5 Billion | WNYC | New York Public Radio, Podcasts, Live Streaming Radio, News." *WNYC*, November 27, 2012. https://perma.cc/5V8N-P4JM.

Houser, Trevor, and Peter Marsters. "The World's Second Largest Blackout." *Rhodium Group* (blog), April 12, 2018. https://perma.cc/9ZEZ-79X2.

"Hurricane Maria Updates: In Puerto Rico, the Storm 'Destroyed Us.'" *The New York Times*, September 21, 2017, sec. U.S. https://perma.cc/U7TQ-MP3U.

Intergovernmental Panel on Climate Change. "Climate Change 2014: Synthesis Report - Summary for Policymakers," 2014. https://perma.cc/E7RZ-QNPF.

———. "Special Report on Global Warming of 1.5°C - Summary for Policymakers," October 8, 2018. https://perma.cc/NP6R-662C.

Jenkins, Jesse D., Max Luke, and Samuel Thernstrom. "Getting to Zero Carbon Emissions in the Electric Power Sector." *Joule* 2, no. 12 (December 2018): 2498–2510. https://doi.org/10.1016/j.joule.2018.11.013.

Joel, Billy. *Miami 2017 (Seen the Lights Go Out on Broadway)*. Turnstiles. Columbia Records, 1976. Miami 2017.

Johnson, Tom. "PSE&G's Scaled-Back Proposal for Upgrading Gas and Power Grids OK'd." *NJ Spotlight*, September 12, 2019, sec. Energy & Environment. https://perma.cc/PSV3-B57X.

Joskow, Paul L. "California's Electricity Crisis." Working Paper. Working Paper Series. National Bureau of Economic Research, August 2001. https://doi.org/10.3386/w8442.

Keellings, David, and José J. Hernández Ayala. "Extreme Rainfall Associated With Hurricane Maria Over Puerto Rico and Its Connections to Climate Variability and Change." *Geophysical Research Letters* 46, no. 5 (2019): 2964–73. https://doi.org/10.1029/2019GL082077.

Klein, Ezra. "Why We Can't Build." *Vox*, April 22, 2020. https://perma.cc/6CNB-M9S8.

Lacey, Stephen. "Resiliency: How Superstorm Sandy Changed America's Grid." Greentech Media, June 10, 2014. https://perma.cc/TEN5-YKVT.

Littell, Jeremy S., Donald McKenzie, David L. Peterson, and Anthony L. Westerling. "Climate and Wildfire Area Burned in Western U.S. Ecoprovinces, 1916–2003." *Ecological Applications* 19, no. 4 (2009): 1003–21. https://doi.org/10.1890/07-1183.1.

Liu, Y. C., P. Di, S. H. Chen, X. M. Chen, and J. DaMassa. "Diablo Winds in the California Bay Area: Their Climatology, Extremes, and Predictability." *AGU Fall Meeting Abstracts* 23 (December 1, 2019). https://perma.cc/V7EV-27D5.

Macwilliams, John J, Sarah La Monaca, and James Kobus. "PG&E: Market and Policy Perspectives on the First Climate Change Bankruptcy." Columbia University Center on Global Energy Policy, August 2019. https://perma.cc/V88A-NQ2V.

Marston, Theodore U. "The US Electric Power System Infrastructure and Its Vulnerabilities." *The Bridge*, National Academy of Engineering, 48, no. 2 (June 15, 2018). https://perma.cc/QP9E-RB8U.

McCollum, David L., Ajay Gambhir, Joeri Rogelj, and Charlie Wilson. "Energy Modellers Should Explore Extremes More Systematically in Scenarios." *Nature Energy* 5, no. 2 (February 2020): 104–7. https://doi.org/10.1038/s41560-020-0555-3.

McMullen, Jane. "Fire in Paradise." *Frontline*. PBS, October 29, 2019. https://perma.cc/4HCD-NN6S.

Meyer, Robinson. "What's Happening With the Relief Effort in Puerto Rico?" *The Atlantic*, October 4, 2017, sec. Science. https://perma.cc/7STY-24SW.

Milken Institute School of Public Health. "Ascertainment of the Estimated Excess Mortality from Hurricane Maria in Puerto Rico." The George Washington University, August 28, 2018. https://perma.cc/Z6R3-QMNJ.

Miranda, Lin-Manuel, and Alex Lacamoire. *Puerto Rico (A Hundred Miles Across)*. Last Week Tonight with John Oliver, 2016. https://perma.cc/L44Q-EJJ9.

Murphy, Phillip D. "Executive Order 28." State of New Jersey, May 23, 2018. https://perma.cc/Z6R3-QMNJ.

National Academy of Sciences, National Academy of Engineering, and National Research Council. *America's Energy Future: Technology and Transformation*. The National Academies Press, 2009. https://doi.org/10.17226/12091.

National Centers for Environmental Information. "U.S. Billion-Dollar Weather & Climate Disasters: 1980-2020." National Oceanic and Atmospheric Administration, 2020. https://perma.cc/B47E-X84E.

National Drought Resilience Partnership. "Drought in California." National Integrated Drought Information System. Accessed May 15, 2020. https://perma.cc/UCJ9-CVSK.

National Hurricane Center. "Tropical Cyclone Report: Hurricane Maria." National Oceanic and Atmospheric Administration, February 14, 2019. https://perma.cc/MHN7-KSKL.

National Research Council. *Disaster Resilience: A National Imperative*, 2012. https://doi.org/10.17226/13457.

National Transporation Safety Board. "Pacific Gas and Electric Company Natural Gas Transmission Pipeline Rupture and Fire - San Bruno, California - September 9, 2010." Pipeline Accident Report, August 30, 2011. https://perma.cc/2JN7-57UJ.

New York State Public Service Commission. "Order Adopting Storm Hardening and Resiliency Collaborative Phase Three Report Subject to Modifications," January 21, 2016. https://perma.cc/W7HR-HL6L.

———. "Order Approving Electric, Gas, and Steam Rate Plans in Accord with Joint Proposal." Case 13-E-0030: Proceeding on Motion of the Commission as to the Rates, Charges, Rules and Regulations of Consolidated Edison Company of New York, Inc. for Electric Service., February 21, 2014. https://perma.cc/Z4QK-DFSE.

Nikolewski, Rob. "CPUC Rules against SDG&E in 2007 Wildfire Case." *San Diego Union-Tribune*, November 30, 2017, sec. Energy. https://perma.cc/7BCJ-HKTE.

———. "Why 2 Other California Utilities Have Joined SDG&E's Push to Make Consumers Pay for 2007 Wildfire Costs." *San Diego Union-Tribune*, October 24, 2017, sec. Energy. https://perma.cc/N76V-YDDM.

North American Electric Reliability Corporation. "Hurricane Sandy Event Analysis Report," January 2014. https://perma.cc/ZE7W-9KC9.

———. "Reliability Terminology," August 2013. https://perma.cc/8DMQ-AXP5.

Obama, Barack H. "Remarks by the President on Climate Change." Georgetown University, Washington, D.C., June 25, 2013. https://perma.cc/67ZV-PFFR.

Office of Cybersecurity, Energy Security, and Emergency Response. "Hurricanes Nate, Maria, Irma, and Harvey Situation Reports." U.S Department of Energy. Accessed May 20, 2020. https://perma.cc/XF63-XXD6.

———. "ISER - Hurricane Sandy." U.S Department of Energy. Accessed May 20, 2020. https://perma.cc/XQ2U-45KV.

Office of Electricity Delivery and Energy Reliability. "Comparing the Impacts of Northeast Hurricanes on Energy Infrastructure." U.S. Department of Energy, April 2013. https://perma.cc/D6LX-8VZM.

Office of Infrastructure Security and Energy Restoration. "Hurricanes Maria, Irma, and Harvey - September 21 Morning - Event Summary (Report #40)." U.S. Department of Energy, September 21, 2017.

Organic Act of 1900, Pub. L. No. 56–191 (1900). https://perma.cc/4G3F-54T9.

Otto, Christian, Franziska Piontek, Matthias Kalkuhl, and Katja Frieler. "Event-Based Models to Understand the Scale of the Impact of Extremes." *Nature Energy* 5, no. 2 (February 2020): 111–14. https://doi.org/10.1038/s41560-020-0562-4.

Pacific Gas and Electric Company. "2020 First Quarter Earnings." May 1, 2020. https://perma.cc/L5UW-M9TQ.

———. "2020 Wildfire Mitigation Plan." 2020-02-28. Accessed May 9, 2020. https://perma.cc/B6HL-QF9C.

———. "Amended 2019 Wildfire Safety Plan," February 6, 2019. https://perma.cc/6PBW-L86M.

———. "Amended PSPS Report to the CPUC - October 9-12, 2019 De-Energization Event." Accessed May 10, 2020. https://perma.cc/72BL-VTVA.

———. "Amended PSPS Report to the CPUC - October 23-25, 2019 De-Energization Event." Accessed May 10, 2020. https://perma.cc/32T9-DQ24.

———. "Amended PSPS Report to the CPUC - October 26 & 29, 2019 De-Energization Event." Accessed May 10, 2020. https://perma.cc/VM88-LZ8G.

———. “Company Profile.” Accessed April 23, 2020. https://perma.cc/KX9T-UA9B.

———. “Correction to Updated Post-PSPS Report for October 5-6, 2019,” February 28, 2020. https://perma.cc/43VB-RLLJ.

———. “Fire Prevention Plan,” December 20, 2012. https://perma.cc/D5UC-TT3J.

———. “Form 10-K, Fiscal Year 2019.” U.S. Securities and Exchange Commission, February 18, 2020. https://perma.cc/A39R-G58A.

———. “Pacific Gas and Electric Company’s Response to Request for Information.” United States of America v. Pacific Gas and Electric Company. U.S. District Court for the Northern District of California, July 31, 2019. https://perma.cc/BCK6-PBLD.

———. “PG&E Fire Incident Data, 2014-2018,” 2019. https://perma.cc/L7HG-F2WN.

———. “Quarterly Advice Letter Pursuant to Assembly Bill 1054 Regarding the Implementation of Its Approved Wildfire Mitigation Plan and Its Safety Recommendations,” April 30, 2020. https://perma.cc/KX9T-UA9B.

———. “Response to Questions to PG&E Re: Late October PSPSs.” United States of America v. Pacific Gas and Electric Company. U.S. District Court for the Northern District of California, November 29, 2019. https://perma.cc/E2NT-FRWR.

———. “Response to Request for Information on PSPS.” United States of America v. Pacific Gas and Electric Company. U.S. District Court for the Northern District of California, October 30, 2019. https://perma.cc/KR5F-74VU.

———. “Service Territory Map.” Accessed May 8, 2020. https://perma.cc/W2E8-DLNM.

———. “Test Year 2020 General Rate Case Application of Pacific Gas and Electric Company.” California Public Utilities Commission, December 13, 2018. https://perma.cc/QFB5-SH8C.

———. “Updates To Post-PSPS Event Reports for June 7-9, 2019,” February 28, 2020. https://www.pge.https://perma.cc/RTZ6-ENR7.

———. “Updates To Post-PSPS Event Reports for September 23-25, 2019,” February 28, 2020. https://perma.cc/LV7U-7JU4.

Pacific Gas and Electric Company, and PG&E Corporation. “Form 8-K.” U.S. Securities and Exchange Commission, March 23, 2020. https://perma.cc/NUA6-8QPR.

Painter, William L, and Jared T Brown. “FY2013 Supplemental Funding for Disaster Relief.” Congressional Research Service, February 19, 2013. https://perma.cc/KY6L-6ZUK.

Penn, Ivan, and Peter Eavis. “PG&E Will Plead Guilty to Involuntary Manslaughter in Camp Fire.” *The New York Times*, March 23, 2020, sec. Business. https://perma.cc/9AVQ-9D4E.

———. “PG&E’s Settlement With Wildfire Victims Faces Crucial Vote.” *The New York Times*, April 30, 2020, sec. Business. https://perma.cc/8KCS-382X.

Penn, Ivan, Lauren Hepler, and Peter Eavis. “PG&E Reaches $13.5 Billion Deal With Wildfire Victims.” *The New York Times*, December 6, 2019, sec. Business. https://perma.cc/D9WT-WYAE.

Public Service Electric and Gas Company. “Clean Energy Future,” September 27, 2018. https://perma.cc/3XP8-3HR5.

———. “Energy Strong II.” *PSEG - Initiatives* (blog), June 8, 2018. https://perma.cc/HA67-47JK.

Puerto Rican Federal Relations Act of 1917, Pub. L. No. 64–368 (1917). https://perma.cc/6CUP-HLHW.

Puerto Rico And Possession Tax Credit [Repealed], Internal Revenue Code § 936 (1976). https://perma.cc/2ZJ9-ZHV5.

Puerto Rico Central Office of Recovery, Reconstruction, and Resiliency. “Grid Modernization Plan for Puerto Rico,” December 13, 2019. https://perma.cc/LW5C-LJRC.

Puerto Rico Electric Power Authority. “2019 Fiscal Plan for the Puerto Rico Electric Power Authority,” June 27, 2019. https://perma.cc/T7KB-T269.

Puerto Rico Energy Commission. “Final Resolution and Order on the First Integrated Resource Plan of the Puerto Rico Electric Power Authority,” September 23, 2016. https://perma.cc/S7B2-MHNW.

Rhodium Group. “New Jersey’s Rising Coastal Risk,” October 2019. https://perma.cc/6ZEB-S9DG.

Rice, Andrew. “The McKinsey Way to Save an Island.” *New York Magazine*, April 17, 2019. https://perma.cc/3R4Z-A4JT.

Romo, Vanessa, and Adrian Florido. “Political Unrest In Puerto Rico After Discovery Of Unused Hurricane Aid.” *NPR*, January 20, 2020. https://perma.cc/4W4H-GURL.

Sanzillo, Tom, and Cathy Kunkel. “IEEFA Puerto Rico: Bad Gas Deal Hurts PREPA Chances for a Turnaround.” Institute for Energy Economics & Financial Analysis, March 28, 2019. https://perma.cc/M6QA-GJHQ.

Scott, Alwyn. “GE Wins Most 2018 Gas Turbine Orders; Mitsubishi Wins on New Technology: Report.” *Reuters*, February 12, 2019. https://perma.cc/5VLF-KDBP.

Scott, Michon. “Hurricane Maria’s Devastation of Puerto Rico.” Climate.gov, August 1, 2018. https://perma.cc/P6GT-DV7Z.

Scurria, Andrew. “Bankruptcy Judge Won’t Stand in Way of PG&E Settlement Vote.” *Wall Street Journal*, April 8, 2020, sec. WSJ Pro. https://perma.cc/2CLQ-V3BQ.

Sepulveda, Nestor A., Jesse D. Jenkins, Fernando J. de Sisternes, and Richard K. Lester. “The Role of Firm Low-Carbon Electricity Resources in Deep Decarbonization of Power Generation.” *Joule* 2, no. 11 (November 21, 2018): 2403–20. https://doi.org/10.1016/j.joule.2018.08.006.

Siemens Power Technologies International, and Siemens Industries. "Puerto Rico Integrated Resource Plan 2018-2019: Draft for the Review of the Puerto Rico Energy Bureau." Puerto Rico Electric Power Authority, June 7, 2019. https://perma.cc/7HTS-5SGL.

Sierra Club. "Nation's Last New Coal Plant Proposal Denied in Georgia," April 14, 2020. https://perma.cc/JJ9X-FSF8.

Smith, Adam B., and National Centers for Environmental Information. "2010-2019: A Landmark Decade of U.S. Billion-Dollar Weather and Climate Disasters." National Oceanic and Atmospheric Administration, January 8, 2020. https://perma.cc/VHX4-MFCC.

Smith, Rebecca, and Cassandra Sweet. "California Fines PG&E $1.6 Billion for Deadly Gas Explosion." *Wall Street Journal*, April 9, 2015, sec. Business. https://perma.cc/W37X-FJSE.

Stewart, Emily. "Trump Restates Puerto Rico Death Toll Conspiracy." *Vox*, September 15, 2018. https://perma.cc/83B2-QGF7.

Sullivan, Laura. "FEMA Blamed Delays In Puerto Rico On Maria; Agency Records Tell Another Story." *NPR*, June 14, 2018. https://perma.cc/9GWF-PBP6.

Summers, J Kevin, Linda C Harwell, Kyle D Buck, Lisa M Smith, Deborah N Vivian, Justin J Bousquin, James E Harvey, and Michelle D McLaughlin. "Development of a Climate Resilience Screening Index (CRSI): An Assessment of Resilience to Acute Meteorological Events and Selected Natural Hazards," 2017. https://perma.cc/6N2Z-CDWT.

Summers, Lawrence H. "The State of the U.S. Economy: Risks of Recession, Prospects for Policy." The Brookings Institution, Washington, D.C., December 19, 2007. https://perma.cc/F94U-YE29.

Sweet, Cassandra. "PG&E Fined $3 Million, Ending San Bruno Explosion Case." *Wall Street Journal*, January 26, 2017, sec. US. https://perma.cc/VAA2-63QM.

Taleb, Nassim Nicholas. *The Black Swan*. A Random House International Edition. Random House, 2009.

The White House. "United States Mid-Century Strategy for Deep Decarbonization," November 2016, 111. https://perma.cc/346C-538J.

Tollefson, Jeff. "Climate vs Coronavirus: Why Massive Stimulus Plans Could Represent Missed Opportunities." *Nature*, March 30, 2020. https://doi.org/10.1038/d41586-020-00941-5.

Trenberth, Kevin E., John T. Fasullo, and Theodore G. Shepherd. "Attribution of Climate Extreme Events." *Nature Climate Change* 5, no. 8 (August 2015): 725–30. https://doi.org/10.1038/nclimate2657.

Tsafos, Nikos. "How Will Natural Gas Fare in the Energy Transition?" Center for Strategic and International Studies, January 14, 2020. https://perma.cc/8KXX-CM5T.

Tweed, Katherine. "PSE&G Takes Over LIPA Operations." *Greentech Media*, May 15, 2013, sec. Grid Edge. https://perma.cc/9CDB-KQQW.

United Nations Framework Convention on Climate Change. Paris Agreement (2016). https://perma.cc/DY8P-2LX5.

U.S. Bureau of Economic Analysis. “Gross Domestic Product.” FRED, Federal Reserve Bank of St. Louis. FRED, Federal Reserve Bank of St. Louis, April 29, 2020. https://perma.cc/BK7R-PKMZ.

U.S. Department of Defense. “Army Committed to Restoring Puerto Rico’s Power,” March 23, 2018. https://perma.cc/EL5S-3P6C.

U.S. Department of Housing and Urban Development. “Rebuild by Design.” Accessed May 15, 2020. https://perma.cc/A52V-H296.

U.S. Energy Information Administration. “Electricity Generation, Capacity, and Sales in the United States,” March 19, 2019. https://perma.cc/8XQ4-WFY6.

———. “Frequently Asked Questions (FAQs) - What Is U.S. Electricity Generation by Energy Source?,” February 27, 2020. https://perma.cc/X9FZ-VJ56.

———. “Net Generation for All Sectors, Annual (Thousand MWh),” 2020. https://perma.cc/6V2R-X4NC.

———. “Puerto Rico’s Electricity Service Is Slow to Return after Hurricane Maria - Today in Energy,” October 24, 2017. https://perma.cc/659J-FN4A.

———. “Table 11.6 - Carbon Dioxide Emissions From Energy Consumption: Electric Power Sector.” Monthly Energy Review, April 2020. https://perma.cc/B2F5-QV4C.

———. “Wind Has Surpassed Hydro as Most-Used Renewable Electricity Generation Source in U.S.,” February 26, 2020. https://perma.cc/M6UG-LLJ4.

U.S. Environmental Protection Agency. “Fact Sheet: Overview of the Clean Power Plan,” August 2015. https://perma.cc/RH4M-3PVB.

———. “Inventory of U.S. Greenhouse Gas Emissions and Sinks: 1990-2017,” April 11, 2019. https://perma.cc/2GBX-K5A7.

U.S. Global Change Research Program, David R. Reidmiller, Christopher W. Avery, David R. Easterling, Kenneth E. Kunkel, Kristin L.M. Lewis, Thomas K. Maycock, and Brooke C. Stewart. “Impacts, Risks, and Adaptation in the United States: Fourth National Climate Assessment, Volume II.” U.S. Global Change Research Program, 2018. https://doi.org/10.7930/NCA4.2018.

U.S. Global Change Research Program, D.J. Wuebbles, D.W. Fahey, K.A. Hibbard, D.J. Dokken, B.C. Stewart, and T.K. Maycock. “Climate Science Special Report: Fourth National Climate Assessment, Volume I.” U.S. Global Change Research Program, 2017. https://doi.org/10.7930/J0J964J6.

U.S. Government Accountability Office. “2017 Hurricane Season: Federal Support for Electricity Grid Restoration in the U.S. Virgin Islands and Puerto Rico,” April 2019. https://perma.cc/C3JC-YMWE.

———. “Puerto Rico: Factors Contributing to the Debt Crisis and Potential Federal Actions to Address Them,” May 2018. https://perma.cc/WYA8-MDUC.

———. “U.S. Territories: Public Debt Outlook – 2019 Update,” June 2019. https://perma.cc/FAS6-4PD9.

U.S. Securities and Exchange Commission. “SEC Charges UBS Puerto Rico and Two Individuals in Actions Relating to Former Broker’s Fraud,” September 25, 2015. https://perma.cc/PKF8-S6GP.

Van Dam, Andrew. “The U.S. Has Thrown More than $6 Trillion at the Coronavirus Crisis. That Number Could Grow.” *Washington Post*. Accessed May 7, 2020. https://perma.cc/S3S6-JSRF.

Van Nostrand, James M. “Keeping the Lights on during Superstorm Sandy: Climate Change and Adaptation and the Resiliency Benefits of Distributed Generation.” *New York University Environmental Law Journal* 23, no. 1 (2015): 92–156. https://perma.cc/XPR2-FF44.

Walsh, Mary Williams. “McKinsey Advises Puerto Rico on Debt. It May Profit on the Outcome.” *The New York Times*, September 26, 2018, sec. Business. https://perma.cc/FL2A-LF2B.

———. “McKinsey Will Return $15 Million in Fees Over Disclosure Failures.” *The New York Times*, February 19, 2019, sec. Business. https://perma.cc/68KK-RYJG.

Walsh, Mary Williams, and Karl Russell. “$129 Billion Puerto Rico Bankruptcy Plan Could Be Model for States.” *The New York Times*, September 27, 2019, sec. Business. https://perma.cc/7HDY-CAF4.

Wernsing, Richard, and Public Service Electric and Gas Company. “Making New Jersey Energy Strong: Reliability & Resiliency in New Jersey.” IEEE PES GM Panel, July 30, 2014. https://perma.cc/YCR3-NDFH.

Wicker, Roger F. Puerto Rico Oversight, Management, and Economic Stability Act (PROMESA), Pub. L. No. S.2328 (2016). https://perma.cc/HE87-JHV5.

Williams, A. Park, John T. Abatzoglou, Alexander Gershunov, Janin Guzman-Morales, Daniel A. Bishop, Jennifer K. Balch, and Dennis P. Lettenmaier. “Observed Impacts of Anthropogenic Climate Change on Wildfire in California.” *Earth’s Future* 7, no. 8 (2019): 892–910. https://doi.org/10.1029/2019EF001210.

Willison, Charley E, Phillip M Singer, Melissa S Creary, and Scott L. Greer. “Quantifying Inequities in US Federal Response to Hurricane Disaster in Texas and Florida Compared with Puerto Rico.” *BMJ Global Health* 4, no. 1 (January 2019): e001191. https://doi.org/10.1136/bmjgh-2018-001191.

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