CONTENTS

Chapter 1

Tech Policy and the Climate Crisis

It was another oppressively sultry August day in Washington, DC, but the atmosphere in the White House was nothing short of jubilant. A last-minute compromise between the renegade Democratic West Virginia senator, Joe Manchin, and Senate Majority Leader Chuck Schumer delivered the deciding hand in the 51–50 vote in favor of what President Joe Biden called "the most significant US climate legislation ever."[1] Models suggested that the 2022 Inflation Reduction Act (IRA) would reduce the country's 2030 carbon footprint by 40 percent relative to 2005: a quantum leap in the direction of a "net-zero" emissions future. No matter that Manchin had insisted on framing the new statute as an anti-inflation measure and not one targeting the scourge of climate change. Everyone understood that the heart of the bill was an unprecedented $369-billion allocation for deploying climate tech and developing low-carbon technologies. The law's disparate tax credits for incentivizing decarbonization are likely to reach far higher sums.

America's return to climate leadership was a great relief for the growing number of people around the world alarmed that global warming was irreversibly damaging the Earth and threatening the future of civilization. The IRA offered validation for those who had long held the belief that the climate crisis could only be solved by rapidly decarbonizing the planet's economy. Such a dramatic transition would not happen without a massive investment in climate tech. The former vice president, Nobel peace laureate, and climate prophet-in-chief, Al Gore, tweeted about "a historic turning point": "It represents the single largest investment in climate solutions and climate justice in US history. Decades of tireless work by climate advocates across the country led to this moment."[2] Biden's former boss, Barack Obama, waxed optimistic: "Progress doesn't happen all at once, but it does happen—and this is what it looks like."[3]

At the same time, there was no shortage of critics who did not buy the underlying assumption of President Biden's visionary climate strategy. The Heritage Foundation, a leading conservative think tank, expressed the umbrage of many opponents:

> These subsidies could shift trillions of dollars of investment away from conventional energy sources and into green energy pipe dreams. This shift would leave our economy smaller, less dynamic, and less innovative, and will trap millions in poverty. . . . Do you like your natural gas stove or fireplace? Well, this bill is part of a broader effort to make these appliances relics of the past. It creates tax credits to have homes run on "clean energy" and for the purchase of "clean vehicles." If American consumers demand those types of products and features, that's one thing. The creation of this tax credit is a recognition that Americans don't desire the products and, therefore, Washington politicians must induce Americans to "do the right thing."[4]

A year later the debate still raged. Republican lawmakers proposed legislation to cancel the IRA before it had a chance to become fully operational.[5] Some politicians still assailed its policies as disgraceful handouts that subsidize elitist technologies for the wealthy.[6] Many American allies, from South Korea to Europe, were furious with the crass protectionism and preferential treatment that the new American climate strategy afforded the local climate tech industry,[7] claiming the policies threatened to set off a clean-energy "arms race."[8] Climate activists fretted that the IRA's support for decarbonization was "too little, too late,"[9] or simply wondered whether any government was capable of accelerating climate innovation fast enough.

The controversies beg two fundamental questions: First, should governments be in the "technology policy" business in the first place? And second, is technology policy an effective way for governments to reduce carbon emissions and confront the climate crisis? If the answers to these questions were not unequivocally affirmative, this book would be very short. Nonetheless, before diving into the clear imperative for government support for technological advancement in general, and decarbonization technologies in particular, it is worthwhile to consider some of the critics' common arguments.

There is no shortage of naysayers who attack the very notion of a systematic, vigorous technology policy, choreographed by a central government as ill-advised and wasteful. They have their reasons: for starters, they challenge the blind assumption that societal investment via government funded research in the private sector will ultimately pay for itself. Governments do not face the pressures to quickly produce favorable economic results that venture capitalists and banks do. This means that public funds may well be invested in ventures that will be less efficient and less profitable than their competitors that can already show lucrative "bottom lines" sufficiently appealing to attract investors. According to this view, government involvement in promoting technologies undermines the rough-and-tumble of free-market competition and assumes that taxpayers' money is less valuable than market-rate capital.

Ideologically, technology policy is anathema for capitalism's true believers. To them, flouting the natural "fair fight" of the free-market undermines the cherished survival-of-the-fittest dynamic on which a healthy economy is based. As they see it, unfettered competition has always been the best guarantor of optimal resource allocation, sound economic decisions, and technological progress. According to this view, the only legitimate role that governments should assume in supporting innovation is ensuring that markets remain open, transparent, and competitive in order to allow "the best technology to win." In the course of human events, market distortions may occur for any number of reasons. But governments should try to minimize them, not perpetuate or exacerbate them through policy that promotes certain technologies. Making the advancement of innovation an integral component of public policy leads to swollen bureaucracies, with all the institutional ambition and hubris that inevitably spawn partiality and wasteful economic decisions.

Another argument against technology policy goes like this: In today's global economy, progress depends on the removal of barriers and the free exchange of ideas. In a post-Covid world where an increasingly high percentage of researchers and developers work remotely, the notion of a country devoting resources to gain a national economic advantage through a particular technological advancement or domination of a manufacturing sector is simply no longer appropriate. A truly *global* economy requires an open, creative, transboundary, and ultimately unobstructed competitive process.

Competence is another source of objections: critics argue that governments are not designed—and indeed lack the capacity—to pick technological "winners and losers." While many talented officials may harbor delusions that they can shape the outcomes of technology development, or that strategic investments in good ideas invariably lead to prosperity, the record suggests otherwise. The technological stagnation that characterized the centralized Communist economies of the past are a reminder of the perils of bureaucratic overreach. Especially in free-market economies, a ponderous government hand at the steering wheel, guiding technological strategy, is unlikely to lead to favorable outcomes.

In the context of climate tech, the case of Solyndra offers a case in point: this Fremont, California–based company offered tubular solar panels that were supposed to be uniquely appropriate for large, low-sloping roofs. Their cylindrical systems were made from copper indium gallium selenide, which the company argued would be more efficient than conventional crystalline silicon. In 2009, as part of the renewable energy boost at the heart of the Obama Administration's economic stimulus plan, the government cosigned $535 million in loans for the company. There was no shortage of warning signs: the founding CEO had left the company; market analysts were wary; Dun & Bradstreet's credit appraisal of the company was a very diffident "Fair."[10] And of course, China was subsidizing its solar manufacturing so much that competing was practically impossible.[11] But the government was on a mission, intent on making a significant financial commitment to renewable energy. Disaster did not take long. Two years later, Solyndra filed for bankruptcy.[12]

The Solyndra debacle raises the political problem of "sunk costs" and bureaucratic momentum. Civil service culture and institutional exigencies don't allow officials to admit when they make mistakes in their use of taxpayers' money. Time after time, governments throw "good money after bad" at projects: from dams and supersonic jets to nuclear plants and synthetic fuels. Conversely, long investment horizons don't jibe well with election cycles: shifting political winds in democratic societies inevitably truncate funding and lead to the collapse of long-term projects.

There are also legitimate concerns about the unintended consequence of crowding out private financial markets. Taxpayer dollars are precious and public coffers limited, making government budgeting a zero-sum game. Tax-funded programs to advance new technologies (when the same innovation might have enjoyed support from the private sector) may come at the expense of underwriting other important civic or social initiatives. Venture capital (VC) will never be able to compete with the government in assuming risks of unproven technologies, taking on long-term investments, or absorbing the losses when an R&D venture goes south. Investors may play it safe and simply opt out, whereas in the absence of government investment, some might have been very willing to step up to the plate and finance a risky new technology.

Technology policy is also disparaged by critics for spawning corruption and favoritism. No bureaucrat is born fully dispassionate and unbiased. Very gifted, persuasive, and well-connected people are paid large sums of money to influence public spending decisions. Even if no money is passed under or over the table, far too often enticements, whether political or material, inform government decisions—generally, not for the better. Even if one holds a less cynical view about the way lobbyists operate, access to decision-makers will never be created equal.

Opponents of government involvement in directing technological development invariably offer "empirical proof" to support their position. American conservative think tanks are particularly good at finding examples of confident bureaucrats wasting unseemly sums of public money to promote technologies that, in retrospect, were always duds. Take the time the city of San Francisco spent over $20,000 on a trash can.[13] And there is the $400,000 self-cleaning toilet for the Washington Metro that never really worked.[14] NASA's exotic inventions for life in space are living proof that the government is not always a paragon of savvy technology development. Should it really cost $125,000 to develop a 3D "pizza printer" that might be used on Mars fifteen years in the future?[15] And of course, the veil of secrecy behind military technologies hides the most grotesque waste of public resources for new weapons system. Consider the $1.7 *trillion* dollars spent since 1995 on the F-35 Joint Strike Fighter jet, which is still not ready to fly.[16]

So go the main objections of technology policy detractors. They may make for good rhetoric. But this jaundiced perspective about government involvement in technological innovation has never had much traction historically. In recent years it has enjoyed less and less influence and is largely dismissed as demagoguery. There are good reasons for this.

The Innovation Imperative

Technology development has been an important part of government activity around the world from time immemorial. Indeed, public commitment to support promising technologies is neither radical nor new. It was America's good fortune that Alexander Hamilton emerged as the dominant voice in economic matters in the formative days of the United States. As early as 1791, Hamilton was outspoken about the need for the government to cast aside *laissez faire* orthodoxy for a range of policies—from tariffs to procurement contracts.[17] In Hamilton's hyperactive mind, government intervention was essential to foster industry in the nascent national economy and make the United States competitive with Europe.

The American government began to allocate funds for technological advancements in weaponry almost from the get-go, starting with the establishment of its Army Corp of Engineers in 1802.[18] Years later, Congress established the Office of Science and Technology Policy in its Department of Industry and Commerce to make sure that the president has the best possible guidance on advances in science and technology in *civilian* matters. This office continues in its mission to "advance health, prosperity, security, environmental quality, and justice for all Americans."[19] On average, the US government spends more than $70 billion a year to fund scientific research and nurture innovative technology. Of course, this is hardly an American phenomenon. A sustained institutional commitment to supporting technological development has been part of national economic strategies in Japan, Israel, and South Korea, as well as across the European Union from Germany and Ireland to Denmark and Sweden—to name just a few. Apparently, these programs enjoy sufficient demonstratable successes to prevail over libertarian skeptics.[20]

Investment of public funds in technological advancement is sound public policy. There are three central justifications for sustained government commitment to technological innovation:

- the critical role of governments in ensuring economic prosperity;
- the responsibility of government to provide public goods; and
- market failures and the need for government intervention to overcome "externalities"—the negative side effects of commercial activity that are not reflected in the cost of products and services.

Economic Prosperity

Economies are driven by four factors that affect the production of goods: natural resources, physical capital, human capital, and technological innovation.[21] Improving these "inputs" leads to higher GDP and greater total prosperity. It should therefore not be surprising that governments take an active role in nurturing *all four* factors. There is a broad societal consensus that allocating tax dollars toward the sustainable development of land, water, and minerals (natural resources), infrastructure (physical capital), and education (human capital) is an appropriate use of public funds. Innovation is no different. Insofar as technological innovation generates economic activity, and economic activity generates social prosperity, investments in expanding a society's technological tool kit is a sound, if not obligatory, use of public funds.

National agencies and programs with a mandate for proactive technology patronage make sense as the relentless velocity of change grows ever swifter, making it imperative for businesses to run ever faster in order to stay in the global game. Even large, seemingly well-managed corporations are not always sufficiently nimble to remain competitive. The decline of Nokia, once the world's preeminent cell phone company, is instructive. By 2010, the Finnish company's market share had begun to hemorrhage as Apple and Samsung came to dominate the smartphone market.[22] There are several reasons for its economic implosion, but chief among them was Nokia's inability to stay apace of the rapidly evolving technologies in the cell phone industry.[23]

While much is made of the global nature of today's economy, there are other forces at play. In a post-Covid world, many countries are wary of becoming too dependent on international markets and are beginning to hedge their bets with homegrown alternatives. Governments are looking to repatriate supply chains and localize innovation. In most economies, this will not happen without policy interventions.

Similarly, if a national government is expected to help sustain its country's competitive advantage, it must ensure that its industries constantly innovate.[24] Wise policy, for instance, played a key but often underappreciated role in supporting the technology advances that led to the rise of the "Asian Tigers"—the booming economies of South Korea, Singapore, Taiwan, and Hong Kong—in the second half of the twentieth century.[25]

Regardless of a nation's particular circumstances, innovation remains one of the most reliable indicators of economic and societal health. Indeed, there are few universal truths as salient as the need to evolve and adapt. Evolution theory was predicated on the axiom that it is "not the strongest of the species that survives, nor the most intelligent that survives. It is the one that is most adaptable to change." This is as true for economies as it is for biodiversity. From Charles Darwin to Jared Diamond, the lesson is plain: Adapt or die.

Providing Public Goods and National Security

National defense is a classic example of a public good because all citizens benefit from it: there really is no way to exclude "non-payers" and prevent "free riders" from enjoying military protection. The same holds true for law enforcement, highways, education, or clean air. Sadly, in a world that favors "the strong," a country's survival is often more a function of military might than economic agility. That's why, historically, the lion's share of government spending on technological innovation goes to ensuring national security. Indeed, the United States spends some $773 billion dollars annually on its defense budget,[26] with a large portion directed to applied scientific research and innovative military technologies.

Aside from providing security, military investments can also yield extraordinary technological advances with applications to civilian life. Afterall, the Internet, nuclear energy, speech recognition software, autonomous vehicles, LED lighting, magnetic resonance imaging (MRIs), and even freeze-dried foods all started as military projects. But even without side benefits to society, the imperative of keeping citizens safe will always drive government investment in R&D.

Addressing Market Failures

The invisible hand of the market does many things well, but it cannot guarantee that the economy will benefit society as whole. For example, knowledge is essentially a public good. Typically, for an inventor to be remunerated for her work, her breakthrough cannot be kept a secret. For most scientists to succeed, their research findings also must be made public. This in turn can create a virtuous cycle or spillover effect, in which other researchers build on a new discovery to create additional innovations. The public surely benefits from this dynamic, but the inventor, or the company that invested in the research, may not. As a result, research to develop a critical technology may be underfunded, producing a less than optimal social outcome.[27]

There are many instances when it becomes the government's responsibility to intervene in order to correct market failures. "Orphan drugs" constitute a classic example. In many cases, narrow market analysis leads pharmaceutical companies to abandon development of a drug that could cure serious but rare diseases. Typically, this happens when fewer than 200,000 people are affected. That's why the US Congress passed the1983 Orphan Drug Act, guaranteeing the pharmaceutical industry sufficient financial benefits to develop innovative medical solutions in such cases.[28] In retrospect, due to this compassionate and rational policy, some 600 orphan medicines for rare diseases have come to market during the past forty years.[29] Because the government stepped in when the market wasn't working, millions of people around the world were given the gift of life.

Much of environmental protection policy is predicated on the notion that economists have a hard time ascertaining the full social cost of polluting activities. The truth is that environmental assets in most transactions are undervalued. This is the case for clean air, healthy oceans, safe drinking water, quiet, uncontaminated land, biodegradable products, and endangered species. As a result, no one is willing to pay for the technologies that should be developed to prevent adverse environmental outcomes—even though the collective societal benefits from doing so greatly outweigh any associated expense.

In cases of market failure, there is a compelling public interest in government involvement to promote a technological solution. And so it was that myriad unaddressed environmental problems gave rise to interventions that spawned key technologies, including biowaste treatment developed by the UK government under its Landfill Directive;[30] new German biodiesel production;[31] wastewater treatment technologies in France;[32] and advanced oxidation processes for treating contaminated ground and surface water, developed by the US federal government in its hazardous waste remediation Superfund program.[33] The damages associated with the climate crisis are orders of magnitude higher. In 2006, London School of Economics professor Nicholas Stern estimated that the total costs of climate change would soon reach 5 percent of annual global gross domestic product; as conditions worsen, the global costs might reach an unimaginable 20 percent of GDP.[34] No subsequent report has changed the persuasive economic rationale for investing in climate tech.

The public has come to rely on the government to ensure that society develops the technology it needs to remain competitive economically and to defend itself. It also expects it to address the many market failures that lead to abandonment of essential technologies. Support for scientific and technological advancement constitutes a critical government function and should be fully reflected in the global strategy to address the climate crisis.

Why Climate Tech Policy Is Different

Promotion of climate tech has many characteristics in common with other efforts to advance technology, but it also has inherently unique dynamics. What then makes climate technology different from other areas of economic development? Climate tech has four unique traits, any one of which justifies particularly creative and aggressive policies for stimulating innovation: externalities, extended development horizons, high costs of early experimentation, and urgency.

Externalities

Climate tech's sluggish initial performance in the late twentieth century constitutes a classic case of "market failure"—when the value of a business venture to society is far higher than its current commercial value, and governments do not intervene. This is a function of externalities, or the "costs and benefits that are not captured in market prices."[35] This divergence is particularly pronounced when it comes to climate tech, which means that sustainable technologies may not be funded by private capital, even when there are powerful societal benefits that justify investment. For example, for years developing photovoltaics and storage made sense ecologically—and economically—in countries importing fossil fuels, but it never happened. Like so many other climate-mitigation challenges, without a price on the greenhouse gases released to the atmosphere, climate tech development will never be sufficiently monetized and will always be undervalued.

It is worth remembering that society has no problem penalizing firms that produce *negative* externalities. The "polluter pays" principal is axiomatic across the world as the basis for civil and criminal penalties in environmental legislation.[36] By the same token, subsidies are appropriate when technologies create *positive* externalities—like the collective benefit gleaned from transitioning to renewable electricity, energy storage, cultured protein, carbon removal, or low-carbon cement.

There are economic formalists who a priori oppose any imposed "internalization of externalities" because they see it as a violation of free-market capitalism. But almost without exception, modern governments accept the notion that the "invisible hand of the market" frequently does not produce optimal results. It is well to quote the late Herman Daily, the World Bank economist turned University of Maryland professor, who quipped, "If the survival of humanity is external to your model, you probably need a new model." Policies that prioritize support for climate tech are also an antidote to the many years of subsidies lavished on the fossil fuel industry with its negative externalities[38]—and an expression of the positive externalities associated with technologies that mitigate climate change.

Extended Development Horizons

Unlike conventional high tech, where developing an app or cyber security software can reach the market in a matter of a year, climate technology takes time. Climate tech is often tightly linked to infrastructure—and infrastructure planning and construction are protracted processes. The problem is that venture capital funds generally are set to run for no more than ten years—and usually far less.[39] At that point, any remaining funds are liquidated, and financiers remunerated. Climate tech entrepreneurs require more “patient investors.”[40] While politicians operate according to short time horizons, government bureaucracies staffed by career civil servants have the ability to take a long-term view.

“Green hydrogen”—that is, hydrogen produced by the electrolysis of water using renewable electricity—offers a good example of just how long this proverbial “valley of death” can be for firms that seek to develop meaningful climate tech innovation. *H2Pro* is a promising Israeli green hydrogen firm that opened its doors in 2019.[41] But the company’s technology is based on five previous years of electrochemistry research by Techion research team Avner Rothschild, Gideon Grader, and Hen Dotan. The team developed an electrochemical thermally activated chemical (ETAC) method for splitting water, a breakthrough that was important enough to be published in *Nature* in 2019. The company’s innovative design is promising indeed: a typical hydrogen electrolyzer is only about 70 percent efficient; 30 percent of the energy used in production is lost as heat. Unlike conventional electrolysis, H2Pro’s process generates hydrogen and oxygen separately in different steps—an electrochemical step and a thermally activated chemical step. This allows for high-pressure production of green hydrogen in a way that retains exceptional energy efficiency (98.7 percent HHV) inside the reactors.[42]

Today, the team has grown from Rothschild’s original four laboratory staffers to 100 workers, and the company is planning to build a factory. All this requires a significant budget, even though H2Pro has yet to produce its first demonstration unit and cannot know for certain whether its unorthodox process will work on a commercial scale. And even if it succeeds in cost-effectively producing green hydrogen at scale, profits will take at least a decade from initial investment to materialize.

Tech investors like to look closely at a product’s “technology readiness level.” The TRL system involves a nine-step progression, developed by NASA during the 1970s, that is useful for assessing the maturity of technologies for acquisition. It starts with basic science and feasibility research (levels 1 and 2) until ultimately reaching system development and system testing (levels 8 and 9). Professor Rothschild characterizes the TRL sequence economically as “essentially a logarithmic scale.”[43] In other words, as a company progresses, moving up through the different technology readiness stages, the costs rise.

The other factor that makes development horizons so long is the need to scale technologies so that prices can drop to economically feasible levels. For a climate tech innovation to be successfully diffused, a lower-cost alternative typically must be available to replace an existing technology. H2Pro is the exception that proves the rule. It succeeded in raising over $100 million dollars from investors including Bill Gates' Breakthrough Energy Ventures and Israeli tech entrepreneur extraordinaire, Talmon Marco. This gave the company the necessary capital to build a commercial-scale facility for producing hydrogen. Presumably, idealistic billionaires have the stamina and the monetary muscle to see this project through.[44] But it is unlikely that conventional VC investors can wait so long or are willing to assume the associated financial risk.

Driving the price of a disruptive technology down to a reasonable level does not happen overnight. But when it happens, it can happen fast. "Wright's Law" was developed to quantify the pace of this process. It was in 1936 that aeronautical engineer Theodore Wright observed a drop in the production costs of airplanes during the preceding decades. Each year, the airframes manufactured became less expensive. As he formulated a historic cost curve, a clear pattern emerged: for every doubling of production, Wright saw a steady 15 percent reduction in costs.[45]

The same trend holds for climate technology: "Swanson's Law" is the renewable energy equivalent, named for Richard Swanson, the Stanford University engineering professor and founder of SunPower, a solar photovoltaic cell manufacturer. The first solar cell was invented in the United States in 1954. But a year later, Japan made a prototype model of a solar cell and was quick to take the lead in developing the technology. By 1958, Japan had installed its first photovoltaic system, with a generating capacity of 70 watts, at a radio relay station on top of Mount Shinobu. It took another twenty years before photovoltaic electricity systems were connected to the country's power grid: in 1978, Sanyo Electric began installing PV generation systems with the capacity to return the surplus electricity from individual houses to the power supply system. This breakthrough was soon reflected in expanded production. Meanwhile, PV cells were being used by Japanese manufacturers to power calculators. By 1999, Japan was the world leader in the total manufacturing of photovoltaic solar cells and, for a brief period, in PV electricity generation.[46]

Professor Swanson was among the first to demonstrate that solar electricity prices dropped by 20 percent for every doubling in solar panel capacity.[47] Tracking the more recent lowering of prices of solar and wind energy suggests that the price decline has been even more precipitous, reaching as much as 30 percent with every 100 percent increase of installed base.[48] As a result, by 2022 solar energy was 30 percent less expensive than electricity produced by natural gas.[49]

This relative advantage was the result of some forty years of constant multiplying in production.[50] Expanded production and massive deployment of decarbonizing technologies also yields innovation, which is soon manifested in lower costs. This is why it is impossible to separate general climate-mitigation policies from climate innovation. Programs to reduce greenhouse-gas emissions through deployment of clean technologies arguably constitute the single most powerful driver of climate tech R&D.

Moreover, for private capital to gain a reasonable return on investment, innovation has to have a large enough technological "moat" to ensure exclusivity. Many solutions, even if viable and marketable, are simple and easy to emulate. This makes them poor candidates for venture capital. Take, for instance, meat alternatives, which are much less carbon-intense than animal protein. One of the reasons why many analysts believe that Impossible Burger will ultimately beat Beyond Meat in the battle for preeminence in the plant-based protein niche is that the latter is based on technology which is relatively easy to copy.[51]

All this means is that climate tech promotion is simply a great place for public policy to shine. Government involvement is critical for providing the oxygen for completing the many long-distance runs that will be needed to reach the finish line in humanity's race to a sustainable economy. If designed correctly, policies can provide numerous ways for making VC investment more compelling.

The High Cost of Early Experimentation

It is estimated that only about 1,000 of the 500,000 new startups each year in the United States succeed in receiving first-round venture capital funding.[52] That's because startups in general are a risky business; with its high incubation requirements, climate tech is even more so. As part of a *derisking* strategy, many venture capitalists like to frame technology startups as early-stage experiments. Presumably, the aspiring company constitutes a hypothesis. Like any theory, it can be tested through an iterative experimentation process, with benchmarks of success or failure along the way.[53] For instance, whether a protein substitute will appeal to consumers can be tested for a lot less than the cost of building a factory. As the product proves its marketability, financing becomes easier. Still, meeting meaningful benchmarks can be costly.

The case of Quidnet Energy is instructive. The California-based startup has developed a unique geomechanically pumped energy-storage system. Given the cost and the solid-waste challenge posed by lithium and other battery technologies, the Quidnet system offers a promising response to the intermittency of renewables. The idea, at least in theory, is simple: when solar or wind systems produce a surfeit of electricity, the system pumps water from a pond, down a well, into a body of rock. As soon as electricity is required, the well is then opened so that the pressurized water can pass through a turbine to generate electricity. The water then returns to the pond for the next cycle.[54]

Quidnet was established in 2012, but like so many climate tech startups, it had difficulty attracting venture capital. By 2016, it was stuck. For the company to move forward to the next stage in its development, a field trial was required for proof of concept. There was no guarantee that the test would succeed. Company engineers saw it as a binary, up-front risk: immediately upon its completion, they would know whether their system worked . . . or not. Unfortunately, the cost of the decisive test came to roughly a million dollars. Not surprisingly, no one was volunteering to pay for it. Ultimately, civil society became engaged. Prime, a newly formed NGO created precisely for this purpose, raised money from two foundations to conduct the test.[55] Using retired Texas oil wells, the trial was conducted and proved successful, allowing the company to proceed with subsequent seed rounds.

Private philanthropy can certainly play a role in combating climate change. Yet early-stage experiments designed to reduce uncertainty and allow startups to move to the next stage in their development are costly, demanding resources far beyond most foundations' capacity. A Harvard University Business School case study about entrepreneurial experimentation concluded, "The very long time-frames and costs associated with learning about a new way to produce clean energy, or different approaches to curing cancer, create a dearth of experimentation, despite intense societal interest."[56] Government involvement to help support and validate the testing is essential for reducing uncertainty and catalyzing investment from the naturally cautious private sector.

Urgency

As society confronts the climate crisis, momentum matters. Yale law professors Zachary Liscow and Quentin Karpilow describe its importance in terms of a process they call "innovation snowballing." This means that innovation builds on itself over time; present innovations will make future ones even more effective and more valuable.[57]

If smart decisions in climate policy are made today, presumably the next generation will be in a better place to realize the next technological phase when it reaches the gun lap in humanity's race to net zero—when a balance is reached between the greenhouse-gas emissions released into the atmosphere and those taken out. If, however, today's generation fails to act, the potential to develop the technologies necessary for a sustainable planet in the future will be diminished.

Unfortunately, talking about the future has proven to be lousy strategy for galvanizing a bold public response to the climate crisis. At the individual level, people see their children and intuitively understand who will benefit from their efforts to decarbonize. But at an amorphous, societal level, "intergenerational justice" is a much harder sell. To inspire greater commitment to combat climate change, advocates often employ military metaphors.[58] Societies at war presumably offer proof positive that if people would only understand what's at stake, they would make the necessary individual sacrifices (and governments would make the investment) required to arrive at an economy with net-zero carbon emissions—even far earlier than the 2050 target. If Americans were willing to plant Victory Gardens during World War II, surely today they should be willing to install double-glazed windows in their homes and photovoltaic systems on their roofs.

This rhetoric resonates nicely but has not proven to be persuasive. There are many reasons why. A decade ago, Canadian professor Robert Gifford identified twenty-seven psychological barriers that explain why people in general—and presumably decision-makers as well—do *not* feel compelled to act to decarbonize, even in the face of mounting evidence that immediate and radical action is necessary: mistrust, behavioral momentum, limited cognition, social comparisons—the list of explanations goes on and on.[59] Each barrier constitutes another reason why governments are going to have to step up and accelerate the speed of climate tech development.

If the public and its representatives would only listen to scientists, presumably commitment to development of climate technology would increase dramatically. This may be starting to happen, but it certainly is not happening fast enough. In 2018, the United Nations Intergovernmental Panel on Climate Change (IPCC), a generally cautious consortium of independent climate experts, released a special report in which its usual vagueness was replaced with refreshing, if alarming, specificity: in order to avoid a temperature increase exceeding 1.5°C, the world needed to reach an interim 45 percent reduction in global carbon dioxide (CO_2) emissions within twelve years.[60] Unfortunately, since that time, release of CO_2 has actually continued to rise, which makes achieving this goal increasingly unlikely. Many of the key technologies required to move the planet toward such targets still need to be developed, but they lack funding.

Whether because of complacency, myopia, or selfishness, humanity has not internalized a true sense of urgency about the crisis. Neither has the international community. Representatives of 200 countries convening at the 2023 UN climate conference in Dubai (COP28) resisted demands from leading scientists and climate activists to begin a phase-out of oil, coal and natural gas, and merely calling for the "phasing out of inefficient fossil fuel *subsidies* that encourage wasteful consumption."[61] (Even so in contrast to the earlier gatherings, the Dubai decision recognized that global greenhouse gas emissions needed to peak "at the very latest" by 2025 if global warming was to be limited to 1.5 degree C.[62]) The ability of individual countries to influence the international agenda and United Nations Framework Convention on Climate Change (UNFCCC) targets appears to be limited, but there is no reason why those countries cannot support climate tech ventures within, or even beyond, their own borders.

Quite simply, unlike the other problems the world faces that require technological solutions, for the foreseeable future global warming appears to be irreversible. This makes the task of developing climate tech far more urgent. Innovation experts generally estimate that technologies discovered today are likely to have their biggest impact two to three decades later. Unfortunately, humanity is in a race against time. Experts warn that if global warming continues, before long the planet will cross key tipping points that will set off a cascade of catastrophic consequences.[63] To stop global warming, technologies that can scale far faster must be found.

Martin Luther King's call to arms from sixty years ago is entirely relevant to the present situation: "We are now faced with the fact that tomorrow is today. We are confronted with the fierce urgency of now. In this unfolding conundrum of life and history there is such a thing as being too late."[64]

Public Policies to Promote Climate Tech Innovation—What's on the Menu?

If government is justified in advancing climate tech, the question becomes: What innovations should it back and how should it support them? Just as the technologies required to move to net zero are hardly homogeneous, innovation itself can be broken into at least three different categories.

Incremental innovation improves existing technologies to make them more efficient without fundamentally changing underlying processes. Like a new model of car or cellular telephone, the new products are just a little better or a little less expensive than the previous version of the product or service. *Disruptive innovation* refers to more-profound changes in specific technological functions, without modifying the underlying system or technological regime.[65] The new product may create a completely new market. The transition from typewriters to word processors or incandescent to LED lighting are good examples. Finally, there is *radical* or *transformational innovation*. This phenomenon is relatively rare. Technologies central to an economy experience a fundamental shift such as the move from steam power to the internal combustion engine, or the Internet, which changed the entire nature of commerce and communications, or the transition that has already begun from internal combustion to electrically powered vehicles.[66]

It is not surprising, therefore, that different policy interventions are required to stimulate different kinds of climate technology transitions. Moreover, the needs of small companies and startups are fundamentally different from those of well-established industries. In the area of climate mitigation, there is no "one size fits all" policy alternative. Rather, a broad range of instruments needs to be applied to address the many pathologies that contribute to the climate conundrum.

One way to think about the various necessary approaches is to differentiate between policies designed to develop new technologies versus those designed to deploy existing technologies and make them affordable. It is critical that financial support for climate tech development be provided alongside incentives to meaningfully expand the *supply* of innovative low-carbon alternatives. An entirely different array of policies is required to increase *demand* for them.[67]

On the technology *supply* side are policies like the following:

- Direct government funding and subsidies for research and development;
- Tax credits and economic incentives to support the activities of climate tech companies in different stages of development;
- Patenting and protection of intellectual property for climate mitigation;
- Facilitating cooperative relationships between researchers and the private sector, including the establishment of technology incubators.

On the *demand* side are programs such as

- Carbon taxes and greenhouse-gas emissions trading systems;
- Tax exemptions and tariffs to incentivize decarbonizing technologies;
- Government procurement directives that prioritize purchase of climate tech products;
- Technology-forcing prescriptions that require adoption of a low-carbon technology;
- Carbon contracts for differences (described in chapter 5), in which governments change the economic calculus by covering the cost differentials associated with relatively expensive but promising new technologies; and
- Softer policy interventions, such as green labeling or disclosure requirements, that can gently nudge industries toward innovation and better climate performance.

The following chapters consider these alternatives and their design: what they are intended to do theoretically and what they actually do. While it is true that the "devil is in the details"—excessive detail and nuance can be devilishly numbing. So, in the following pages, the focus is on the big picture, basic principles, approaches, and outcomes from disparate programs. (Conscientious readers who wish to wonk out and take a deeper dive will have an easy time doing so by following the references.)

There are innumerable climate tech stories that demonstrate the soundness of different policy approaches. Because it constitutes the largest single source of greenhouse gases, decarbonizing electricity justifiably was the first climate challenge embraced by most countries. But it is only Act One in the larger drama that needs to unfold as humanity strives to save its planet. This book also considers how policies can support innovation in sectors that are proving hard to abate but are critical to achieving a net-zero economy.

Climate tech maven and podcast host Shayle Kann calls these sources "the eight horsemen of the Apocalypse": steel, aluminum, cement, chemicals, aviation, shipping, trucking, and chemicals. Together, they constitute roughly a third of total global emissions. The food system contributes another 25 percent; transportation probably 24 percent. Without effective government interventions, their relative contribution to the greenhouse-gas burden will surely grow in the coming years as emissions from electricity continue to drop.

But trend is not destiny. Sound policies can harness the world's abundant competence, creativity, and growing commitment to climate stability in order to hasten innovative solutions.

Chapter 2

A Global Framework for Mitigation

Few climate activists recognize the late British prime minister, Margaret Thatcher, as a champion of the cause, but in hindsight, it is fair to say that no world leader did more to bring early attention to global warming than the "Iron Lady." Thatcher was an unlikely figure to play a critical role in international climate politics. Throughout her tenure in office, she showed a visceral dislike for excessive regulation, opposed environmental initiatives of the European Community, and was an avid supporter of nuclear energy.[1] But as a young woman at Oxford, Thatcher had studied chemistry, and she retained an appreciation for science and scientists. When efforts to reign in chlorofluorocarbons (CFCs) and other ozone-depleting chemicals stalled, the prime minister used her formidable influence to upgrade international commitments and accelerate phaseout.[2]

This was about the same time that scientists were reaching the conclusion that the climate was changing. It is ironic that it took some time for the international community to get used to the notion that the world was getting warmer, not colder. During the 1970s, many serious scientists believed that pollution was leading to a new ice age.[3] But after British experts briefed Thatcher about the dangers of rising temperatures, she concluded that the issue could no longer wait.[4]

Every year, world leaders convene in New York to address the United Nations General Assembly. In 1989, after ten years at the helm of the United Kingdom, Thatcher astonished the attendees at the UN plenary when, out of the blue, she devoted her entire address to a crisis that was, at the time, largely unknown. After presenting some of the evidence about "the greenhouse effect," she called for action:

> The most pressing task which faces us at the international level is to negotiate a framework convention on climate change—a sort of good conduct guide for all nations. Fortunately we have a model in the action already taken to protect the ozone layer . . . that aims to prevent rather than just cure a global environmental problem. . . . But a framework is not enough. It will need to be filled out with specific undertakings, or protocols in diplomatic language, on the different aspects of climate change.
>
> These protocols must be binding and there must be effective regimes to supervise and monitor their application. Otherwise, those nations which accept and abide by environmental agreements, thus adding to their industrial costs, will lose out competitively to those who do not. The negotiation of some of these protocols will undoubtedly be difficult. And no issue will be more contentious than the need to control emissions of carbon dioxide, the major contributor—apart from water vapour—to the greenhouse effect. We can't just do nothing.[5]

By the time the United Nations "Earth Summit" convened at Rio de Janeiro three years later, Thatcher had unceremoniously resigned, but her words proved prescient: a draft Framework Convention for Climate Change had already been negotiated and prepared for adoption. Delegates had been aware of disconcerting reports by the newly created Intergovernmental Panel on Climate Change (IPCC). This consortium of leading climate scientists had been formed in 1988 by the World Meteorological Organization, along with the United Nations Environment Programme, and was later endorsed by the United Nations General Assembly.[6] Its avowed purpose was to "provide policymakers with regular scientific assessment on the current state of knowledge about climate change."[7]

Treaty negotiations were acrimonious: developing countries were naturally disinclined to take action for a problem caused by the fossil fuel economies of wealthy Western countries. Eventually a compromise was reached, whereby the convention recognized countries' "common but differentiated responsibilities" in addressing the problem. This basically set the tone for the next three decades, during which the international community began to muddle forward toward decarbonization, while the global South was exempted from concrete actions to control emissions.

Thatcher and the original United Nations Framework Convention on Climate Change (UNFCCC) leadership could not help but be informed by the concurrent efforts of the international community to address stratospheric ozone depletion. A group of roughly a hundred chemicals was destroying the protective layer that shielded the Earth from the sun's ultraviolet radiation. Fortunately, relatively innocuous chemical substitutes for most of the pernicious CFCs were already being developed. It made a lot of sense for countries to simply adopt a "top-down" approach and force industry to use these substitutes to replace the halogenated compounds that were creating the "ozone hole." As far as international ecological challenges go, reversing stratospheric ozone depletion was looking like the ever-elusive environmental "quick win."

And so it was that the 1992 UNFCCC came to emulate the ozone-depletion agreement's top-down approach. All that was required was for the world's governments to prepare national programs to mitigate climate change by replacing sundry sources of anthropogenic greenhouse-gas emissions. The first generation of climate diplomats quickly learned, however, that climate change was thornier than the world's other ecological challenges. After all, there was no getting around the fact that the entire global economy was based on fossil fuels. Cutting emissions would require the development and widespread adoption of new technologies. Indeed, the agreement brokered at the 1992 summit, the United Nations Framework Convention on Climate Change, specifically calls for signatories to "Promote and cooperate in the development, application, and diffusion, including transfer of technologies, practices, and processes that control, reduce, or prevent anthropogenic emissions of greenhouse gases . . . in all relevant sectors, including the energy, transport, industry, agriculture, forestry, and waste-management sectors."[8]

In retrospect, the treaty's implicit assumption—that the global community could compel countries to both come up with climate-friendly technologies and then integrate them into every aspect of their economies—was naïve. Extremely naïve.

Given the difficulty of mandating this type of sweeping change, it is important to ask whether (and how) the international community—and in particular the United Nations climate accord—have actually influenced the development and adoption of technologies as well as policies to reduce emissions. To what extent does international coordination inform the scientific research agendas required for new advances? And what more should global cooperative initiatives do to accelerate climate innovation and ambitious climate policy?

A Global Crisis

One of the most significant barriers to the global adoption of climate tech is that, currently, it pays to pollute. Countries that are complacent about reducing greenhouse-gas emissions can produce goods more cheaply than their more conscientious counterparts, which means they have a leg up in international trade. It also means that over time, more and more products will be manufactured in countries with lax standards— reflecting a proverbial "race to the bottom."

In fact, as Oxford professor Dieter Helm points out in his book *Net Zero: How We Stop Causing Climate Change*, national governments' decarbonization efforts can end up being counterproductive if they fail to consider the global context. For instance, if a country with strict manufacturing regulations closes down a domestic factory to reduce its own emissions, it may well result in citizens buying more products from companies based in nations with more lenient regulations, leading to an end result of more total emissions. Decision-makers would do well to remember that *net-zero consumption* ultimately matters far more than *net-zero carbon production*.[9] This can only be achieved by policies that go beyond regulation of local sources of greenhouse gases.

Fortunately, countries are increasingly cognizant of these dynamics and are developing policies to eliminate the phenomenon, commonly known as "leakage." This refers to situations when businesses transfer production to countries with less stringent emission constraints. Border taxes (or as the European Union euphemistically calls them, "adjustments") are already on their way. These taxes extend the EU's domestic price on carbon emissions to imports, sending a message that Europe is no longer willing to blithely accept products with a high carbon footprint from countries that are complacent about decarbonization.[10]

Encouraged by environmentalists and industrialists alike, Europe's Carbon Border Adjustment Mechanism began its transitional phase on October 1, 2023. Initially, importers of goods whose production is carbon-intensive—with a significant risk of leakage (cement, iron and steel, aluminum, fertilizers, electricity and hydrogen)—only need to measure and report the direct and indirect greenhouse-gas emissions embedded in their imports.[11] As of January 1, 2026, however, they will be charged the full market price as set by the weekly EU auctions for tons of CO_2 emitted. That's not a second too soon.

The European Commission explains that "by confirming that a price has been paid for the embedded carbon emissions generated in the production of certain goods imported into the EU, the carbon border adjustment mechanism will ensure the carbon price of imports is equivalent to the carbon price of domestic production, and that the EU's climate objectives are not undermined."[12] Future environmental historians may look back to 2026 as a landmark year for global governance of climate mitigation. But the idea is not entirely new.

It is rarely noted that California has been implementing a border adjustment policy for years. When the California Global Warming Solutions Act was enacted in 2006, almost 18 percent of the state's electricity consumption came from outside its borders. It turned out that more than half of the carbon emissions associated with the out-of-state imports came from power plants with high greenhouse-gas emission intensities.[13] California does not have authority to regulate out-of-state power plants. But its leadership realized that it needed to do something to address the perverse incentives encouraging production of lower-priced, high-carbon electricity outside its jurisdictional boundaries.[14] The rules were amended: when imports come from states that don't have a trading system linked to California's standards, the emissions trading system began to require "first deliverers" of imported electricity to offset carbon emissions from electricity through compliance obligations.[15] This may not entirely solve the "resource shuffling" problem (whereby renewably generated electricity is diverted to a jurisdiction with tougher carbon standards and polluting energy sources are then supplied locally).[16] But it's a start.

Border adjustments have another upside. According to one estimate, such a levy will generate $32 billion annually for Europe's coffers. For countries that are slow to adopt tough greenhouse-gas emissions standards, such policies will soon start to change the calculus at the national and the firm level. Border adjustments may succeed in setting a de facto international price on carbon, giving global carbon markets a major boost.

While the EU, or individual countries, can unilaterally adopt such policies, international agreements offer another way to level the playing field. For instance, the global community could adopt mandatory international standards for minimum energy performance in appliances. Such standards already exist for aviation safety, drugs, and even weapons that cause unnecessary or unjustifiable suffering. There is no reason why climate security should be valued less than personal safety.

The same is true of standardizing electric vehicle charging stations, especially since competing plugs have been developed for vehicles in the United States, Japan, China, the EU . . . and the Tesla universe.[17] Cars and trucks cross borders. The present chaos only aggravates drivers' anxiety about the range their vehicles will be able to drive.[18] Similarly, why not include carbon standards on agricultural imports? Afterall, pesticide standards for food traveling across borders have been around for years.[19]

At the heart of these approaches is the recognition that climate change is a global problem; greenhouse-gas emissions do not adhere to national borders. To wrestle them downward, the international community must work together to decarbonize. This requires a global platform for transboundary coordination and governance. For over thirty years, the UNFCCC evolved as its member nations aspired to meet the myriad challenges presented by climate change.

The Long Road to Paris

In 1997, five years after 154 countries formally first signed the UNFCCC, it was clear that very little had taken place to stabilize atmospheric concentrations of greenhouse gases. Yet the accord was designed to be iterative. Each year since its ratification (aside from 2020, due to the global pandemic), signatories have convened at a "Conference of the Parties," otherwise known as the COP, to review and amend the agreement. A significant two-year effort went into preparations for COP3 in Kyoto, yielding the first protocol approved as part of the UNFCCC process. It was an ambitious agreement—sadly, though, given the politics of the time, too ambitious.

The 1997 Kyoto Protocol contained binding emission-reduction targets for developed countries, which were to come into force by 2005. When aggregated, they were expected to reduce signatory greenhouse-gas emissions in 2012 by 5.2 percent—relative to 1990 levels. With few exceptions, most signatories to the UNFCCC immediately agreed to take on this level of commitment. But those who opted out were important ones: the United States and Canada. At the time, China and India were still considered developing countries, making them exempt from mitigation obligations under the Protocol. Combined, they emitted almost half of the greenhouse gas released into the Earth's atmosphere. The result was one of international environmental law's greatest disappointments.

Nevertheless, one significant contribution of the Kyoto Protocol is that it legitimized international emissions-trading programs, which until then had been limited to domestic air pollution schemes. The Protocol (which for fifteen years was still binding for many countries) allows conscientious parties that *exceed* their emission-reduction targets to sell excess emissions allowances to countries that fail to meet theirs. Besides the EU emissions trading system, numerous national or subnational frameworks for buying and selling carbon have since emerged in Canada, China, Japan, New Zealand, South Korea, Switzerland, and parts of the United States.

The failure to translate the Kyoto Protocol's lofty vision into meaningful global decarbonization is often attributed to the abdication of American leadership. The Republican Party, highly influenced by oil interests, controlled the US Senate, the advice and consent of which were required to ratify the American-brokered agreement. Moreover, many Democrats were also not with the program. Prior to the adoption of the Kyoto Protocol, the Senate passed a resolution introduced by influential West Virginia Democratic senator Robert Byrd by 95–0, rejecting the Protocol if it did not include commitments from developing countries. The Senate wasn't really thinking about the weather anyway. Most of its attention was focused on using White House scandals to bludgeon and impeach a weakened President Bill Clinton. Decarbonization, politically, was a nonstarter. But beyond American political pushback, the Kyoto accord had several other fundamental flaws.

In 2012, Dieter Helm penned a thoughtful autopsy for the protocol in the distinguished journal *Nature*:

> The reasons for the Kyoto Protocol's ineffectiveness are in its architecture. It is based on carbon production, not carbon consumption. It has a mainly European focus. It does nothing to address the immediate problem of global coal burning. It is wide open to free-riding, allowing nations to avoid cutting emissions while others do so, and it has few enforcement mechanisms. These are deep flaws that render the protocol incapable of slowing emissions, let alone reversing them. Fortunately, other, better, bottom-up approaches hold hope for progress.[20]

With the feeble performance of the Kyoto Protocol increasingly apparent, other baby steps were made at subsequent UNFCCC gatherings convened annually around the globe. The bottom line, however, remained unchanged: globally, greenhouse-gas emissions continued to steadily increase. It would take almost two additional decades for the international community to internalize the lessons of Kyoto, accept the limitations of a consensus-based model, and come up with something entirely different. And so it was: with the Obama administration applying the full force of America's global influence, the Paris Agreement was signed at COP21 in 2015.

In order to prevent the worst consequences of global warming, negotiators managed to agree on a ceiling for future temperatures: "limiting global warming to well below 2 degrees Celsius above pre-industrial levels and to pursue efforts to limit the temperature increase to 1.5 degrees Celsius."[21] They also agreed on a different strategy for motivating countries to take action.

In lieu of the international community imposing monolithic emissions reductions, every country was expected "to prepare, communicate, and maintain successive nationally determined contributions (NDCs) that it intends to achieve. Parties shall pursue domestic mitigation measures, with the aim of achieving the objectives of such contributions."[22] In other words, every country needed to figure out what it could do to reduce emissions, how it would do it, and then inform the international community of its contribution to the global effort.

Even before the parties convened in Paris, two years of arm-twisting by US secretary of state John Kerry led to an extraordinary achievement: by the time COP21 opened in 2015 in Paris, prior to the start of the deliberations, 150 countries had already submitted "Intended" National Determined Contributions. In terms of rhetoric, the Paris Agreement was zealous in its support for developing new decarbonizing technologies. Article 10 (1) of the agreement emphasizes one of the rare areas where a true consensus exists among the otherwise highly divided UNFCCC member countries: "Parties share a long-term vision on the importance of fully realizing technology development and transfer in order to improve resilience to climate change and to reduce greenhouse-gas emissions."

Despite the sense of triumph among the diplomats at successfully hammering out a meaningful agreement after years of frustration, the new climate accord engendered no shortage of criticism. By design, the Paris Agreement is not prescriptive. (That way, President Obama could forego Senate approval and thus avoid repeating the Clinton Administration's Kyoto Protocol debacle.) Countries pick their own targets, set their own baseline dates, and take them as seriously (or as insouciantly) as they please. Only reporting is legally binding—and most countries were already doing that.[23] So it was not surprising to discover that when the reduction commitments were totaled up and plugged into climate models, experts found that by the end of the century, average temperatures on the planet were still likely to increase by 3.1°C.[24] Defenders of the new approached explained that, at least now, there was a baseline and point of departure for the planet with specific emission reductions pledged that could be ratcheted down over time.

This voluntary, "bottom-up" approach continues at the time of this writing. Most countries recognize both the limitations of the UNFCCC framework and the space it creates for diverse nations at the negotiating table.[25] For instance, at the 2022 COP27 in Sharm El Sheikh, the UNFCCC recognized the "Loss and Damages" suffered by developing countries due to historic emissions of developed countries.[26] Even if largely symbolic, such decisions contribute to a sense of global solidarity that is necessary to keep many countries engaged.

While the framework can help create consensus, it also engenders intense disagreement between nations. No issue is more consistently disputed than financing. In 2009, parties at the Copenhagen COP15 committed to raising $100 billion per year by 2020 for climate aid to developing countries and for the purpose of "meaningful mitigation actions and transparency on implementation."[27] The amount of funding transferred to the Green Climate Fund to support climate action and deployment of low-carbon technologies steadily increased over the years, but never reached the full $100-billion pledge. When shortfalls between 2013 and 2020 were tallied up, climate funding fell 48 percent below what the international community had promised.[28] Most of these funds are provided as loans anyway. Asian and middle-income countries thus far have been the main beneficiaries, with the poorest nations left behind. Moreover, a 2022 Danish assessment showed that from 2011 to 2018, a mere 6 percent of climate finance provided by rich countries was "new or additional" to existing official assistance for development.[29]

In 2015, a separate, $10-billion fund sponsored by UNFCCC became operational. The Green Climate Fund was created to provide grants to developing countries. For instance, it contributed $154 million to a solar energy project in Zambia that produced two fifty-megawatt power plants; financed upgraded grid infrastructure, photovoltaic systems, and energy storage solutions in the Pacific islands; and supported a climate-resilient water-management project in Nepal, along with many, many more worthy initiatives.[30] It's not a short list. But ultimately, the Green Climate Fund's resources remain woefully inadequate. In 2023, eight years after its establishment, a total of $11.3 billion in pledges and contributions had been received.[31]

In the bottom-up spirit of the agreement, the Paris Agreement extended the $100-billion climate funding commitment until 2025. But contributions remain voluntary. And funds collected under these international agreements are *not* earmarked for developing new technologies and innovation: more than three-quarters are directed to mitigation projects. The other quarter of the funds are earmarked for adaptation efforts in developing and middle-income countries. At the 2021 COP26 in Glasgow, the UNFCCC plenary could urge donor nations to increase their relative support for adaptation but do little more.[32] In other words, the wording of the Paris Agreement may offer a bold vision of accelerating green technology, but it offers nothing in the way of funding climate tech research and development. This, however, does not mean that international climate agreements do not affect innovation.

International Commitments

If international climate accords do not designate money for innovation, how then do they help advance the development and adoption of climate tech? It can be persuasively argued that over the years, the UNFCCC, as well as the more recent NDC process, has created pressure to develop new technologies to meet mitigation commitments. Among the various mechanisms that help countries move from aspiration to implementation, three are particularly important:

- Increasingly stringent emissions-reduction targets;
- Benchmarks for decarbonizing electricity, most notably *renewable portfolio standards*; and
- International cooperation in research and development.

A deeper dive into each approach suggests that however imperfect, international agreements matter.

One central accomplishment of the Paris climate agreement was that countries were expected to declare national emission-reductions targets, along with dates for these goals to be met. Defining an achievable target, along with a concrete plan for reaching it, was the culmination of decades of work, during which the UNFCCC shepherded greenhouse-gas emissions monitoring programs forward. A well-known adage, "If you can't measure it, you can't manage it," is particularly relevant when it comes to greenhouse-gas emissions. By the time the world convened in 2015 for COP21 in Paris, this quantification process was far enough along in most countries to establish discrete emission-reduction goals with a solid, scientific basis.

Six years later, the COP26 meeting was eagerly anticipated. Under the Paris Agreement of 2015, parties were expected to submit new and enhanced NDCs to the climate convention secretariat by 2020. These needed to contain more-ambitious greenhouse-gas emission-reduction goals than the original targets. Just how much more, however, was deliberately vague. By the time of the 2021 Glasgow gathering, 151 of the 193 parties had communicated updated or new NDCs. Within a year, 24 more submitted. The vast majority (94.9 percent) of global emissions were covered under these action programs.

The new round of mitigation pledges showed that the level of ambition for reining in emissions continues to vary dramatically between countries. Many countries are no longer stalling but are already transitioning to a low-carbon economy. The United States, of course, represents the most dramatic turnaround.

In contrast to President Donald Trump's dismissive attitude toward global mitigation efforts, at the 2021 Glasgow COP26, the Biden Administration pledged that by 2030 American carbon emissions would be 52 percent lower than in 2005. This was roughly twice the commitment that President Obama was able to make only six years earlier. The EU went a step further, pledging a 55 percent reduction over the same time frame.[33] And in 2020, Denmark's parliament passed a law to reduce climate emissions 70 percent from 1990 levels by 2030.[34]

Not every country has been so forthcoming with its commitments. Responsible for 27 percent of the global greenhouse-gas emissions, China is the world's largest contributor to carbon in the atmosphere. A significant amount (14.6 percent) of those emissions is driven by consumer goods that are exported for foreign consumption; if China's manufacturing hubs constituted a separate country, their CO_2 emissions in 2012 would rank fifth in the world.[35] Nonetheless, the remaining 23 percent of global emissions associated with meeting domestic Chinese needs is still a huge carbon footprint—60 percent higher than the United States, the second-largest emitter. Overall, emissions in China are expected to continue to increase beyond 2030. While the Chinese have promised national "carbon neutrality" by the year 2060, China's leaders' unwillingness to announce what year the country's emissions would peak and begin to fall belies the seriousness of their pledges.[36]

When the projected emissions of each nation were tallied up after the new 2021 "Glasgow" NDC commitments, relative to a baseline of 2010, by the year 2030, global emissions were still set to increase by 10.6 percent. This constitutes a profound disappointment for many, not least the United Nations climate team.[37] After all, there is no guarantee that countries will actually meet their targets, let alone exceed them. Leading up to the 2022 COP27, the UN tried to offer a positive spin on this dour news, reporting that the anticipated increase was a full 22 percent lower than the 13.7 percent rise that was projected just a year earlier.[38] This represents a modest improvement. But clearly it is not good enough.

With such anemic progress, should the world give up on international climate accords? Of course not. Without the UNFCCC's global platform, it is unlikely that any of new targets would have been declared. More importantly, these goals have pushed nations around the planet to begin the process of decarbonization. Proof of the seriousness of America's new commitments can be found in the 2022 Inflation Reduction Act. Its $369 billion for funding energy security and climate-change programs over the next decade is unprecedented. The American government, it seems, is taking international commitments seriously.[39]

The United States is hardly alone. In order for Europe to meet its 55 percent emissions-reduction target and ultimately "become the first carbon-neutral continent on the planet," the EU formally adopted a Green New Deal. This comprehensive strategy promises to transform transportation, manufacturing, electricity, and food systems across the continent,[40] with €600 billion allocated over the next seven years to fund a complete societal makeover.[41] Similarly, by its own admission, Denmark became such a passionate, early decarbonization adopter because of UNFCCC dynamics. After hosting the 2009 COP15 in Copenhagen, it began working on a bold national strategy to reduce emissions from agriculture, industry, and even shipping. By 2020, 80 percent of the power pulsing through the country's electrical sockets came from renewable sources.[42]

The story is the same all over the world. When national leaders realize that they will have to come and make a speech about climate in front of their peers at a United Nations event, even the reluctant can make surprising commitments. Israel, long a laggard in the area of climate mitigation policy, is a good example. Literally on the eve of its delegation's departure to the Glasgow COP in 2021, the government upgraded its emissions-reduction target, pledging to join the growing community of nations committed to becoming carbon-neutral by 2050.[43] Naftali Bennett, Israel's prime minister, candidly acknowledged the role of peer pressure in the decision: "We had to do it sooner or later. So it might as well be sooner."[44]

International accords have also encouraged developing countries to engage in climate mitigation. In 2015, numerous African nations for the first time made commitments to reduce emissions.[45] This process continued at Glasgow with new pledges for decarbonization received from countries like Mozambique,[46] Mauritius,[47] and even "least developed countries" like Ethiopia and The Gambia.[48] South Africa pledged an interim emissions goal 32 percent lower than its NDC in Paris.[49] Bangladesh promised to reduce its total emissions by 6.5 percent by 2030, anticipating that 95 percent of this reduction would take place in the energy sector.[50] If these pledges seem less dramatic than those of the climate champions, perhaps that's because the developing countries' baseline emissions per capita are already so low. Even so, a ratcheting-down process has begun.

One striking phenomenon produced by the Paris Agreement is the high number of countries willing to declare that in the distant future they would become carbon-neutral. By 2023, some 140 countries had committed to a net-zero emissions target by 2050, with China making the pledge for the year 2060.[51] "Net-zero" implies a commitment to balance the total amount of greenhouse

(continued...)

INDEX