Recasting the Golden Key

How Public Finance Can Unlock a Critical Decade of Climate Action

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Suggested Citation

Whitney Mann, Julia Meisel, Paul Bodnar, Ilmi Granoff, *Recasting the Golden Key: How Public Finance Can Unlock a Critical Decade of Climate Action*, Rocky Mountain Institute, 2020, **https://rmi.org/insight/recasting-the-golden-key**.

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The simulation described in this report is available for download at **https://rmi.org/insight/recasting-the-golden-key**.

ACKNOWLEDGMENTS

This report has benefited from the input of over 40 individuals from over 20 institutions. For a complete list of individuals who informed this report, please see the acknowledgments on pages 48 and 49.

FUNDERS

The authors thank ClimateWorks Foundation for supporting this work.

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Rocky Mountain Institute (RMI)—an independent nonprofit founded in 1982—transforms global energy use to create a clean, prosperous, and secure low-carbon future. It engages businesses, communities, institutions, and entrepreneurs to accelerate the adoption of market-based solutions that cost-effectively shift from fossil fuels to efficiency and renewables. RMI has offices in Basalt and Boulder, Colorado; New York City; the San Francisco Bay Area; Washington, D.C.; and Beijing.

A global grantmaker, ClimateWorks Foundation collaborates with funders, regional and research partners, and other climate leaders to strengthen philanthropy's response to climate change.

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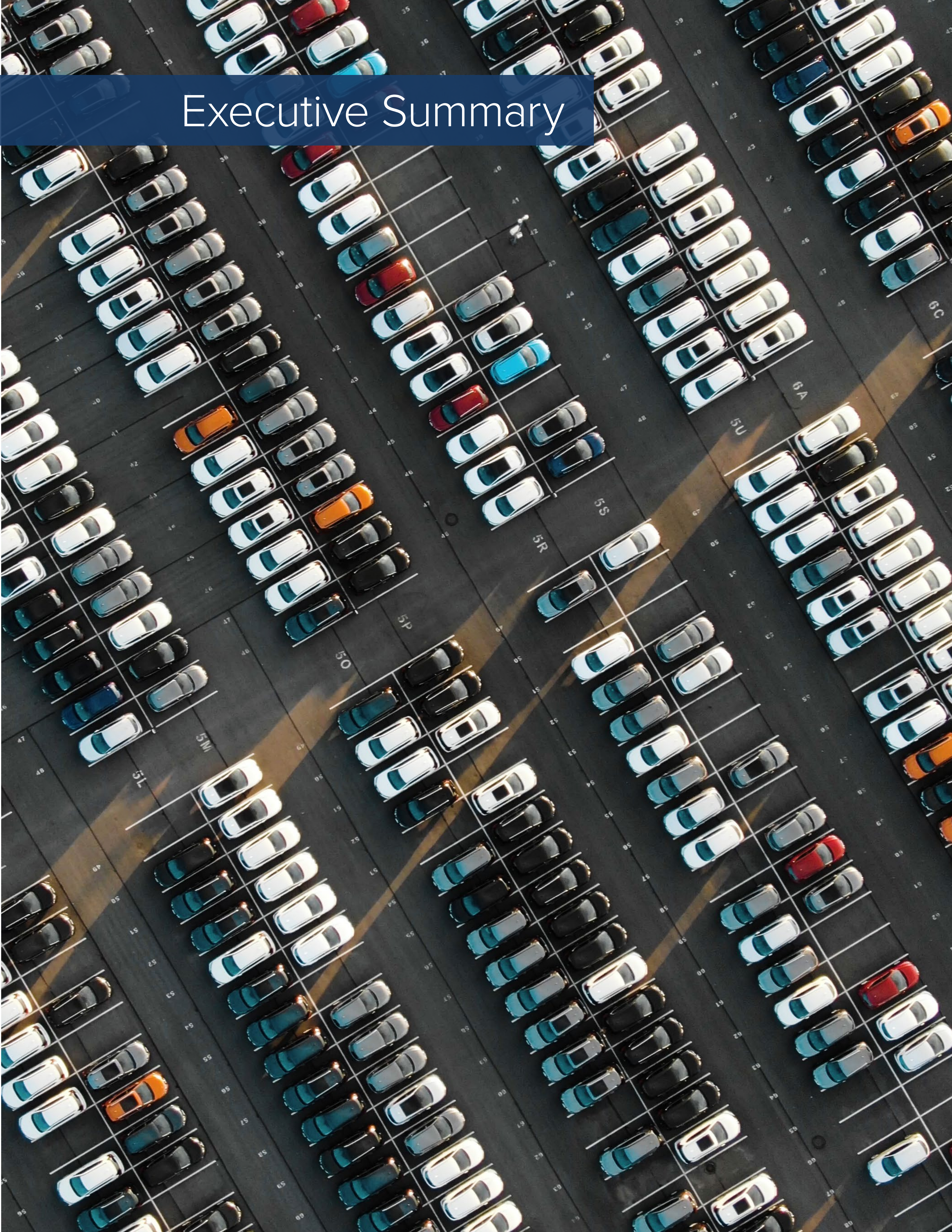


Executive Summary

Climate action is a race against time, with a narrow window to enact a global transition. We know what we need to do: replace the high-emitting assets that provide essential services like light, heat, and mobility with low-carbon alternatives in a just and inclusive manner. Doing so will require cultivating cost-competitive alternatives in sectors as varied as power, transportation, buildings, and industry, as well as fostering the enabling environments to facilitate and sustain their uptake globally. By driving cost reductions for urgently needed technologies and fostering tipping points to enable their widespread adoption, concerted global investment can drive structural change by bringing clean solutions across the economy to market.

But humanity is running out of time: every year of stalled status quo significantly reduces the probability of holding warming below 1.5°C or 2°C. We must cut global carbon emissions by roughly half by 2030 to stay on track for mid-century decarbonization. In the face of such an immense challenge, we need all aspects of our climate action system to maximize their contributions to decarbonization.

Public finance is the "golden key" to unlocking and accelerating global progress toward net-zero economies. Yet far too little has been done to optimize the power of public finance within and across nations. Only the combined force of public expenditure and private capital markets can drive the transformation of entire industries, but strategic use of public expenditure can catalyze the development, deployment, and dissemination of essential low-carbon technologies from basic research through to worldwide commercialization. This is especially true in the COVID-19 era as governments undertake fiscal and economic stimulus measures to "build back better" and the state assumes a much greater ownership stake in the supply of goods and services in the economy as a whole.

However, the prevailing approach to allocating public expenditures for decarbonization has been mostly haphazard, slowing progress and introducing excessive costs into the future. Hamstrung by institutions and decision-making tools that are not built to approach expenditures holistically, the status quo lends itself to shortsighted, siloed, and uncoordinated public finance interventions. Domestically and internationally, governments lack a cohesive approach to answer an obvious question: **What is the best way to spend taxpayers' marginal green dollar in service of global decarbonization?**

The pace of global decarbonization can be accelerated and the cost can be reduced based on how and when nations choose to invest precious taxpayer resources. To match the scope and complexity of the challenge, we need a more deliberate and coordinated approach to our allocation of public expenditures. This approach must respond to opportunities and obstacles in the real economy and leverage global complementarity against a collective challenge for shared benefit. This report aims to highlight how governments can deliver more global emissions reductions on a per dollar basis by taking an integrated approach to their domestic expenditures and international decarbonization agendas.

The principle of integrated support for technology development and deployment can be a helpful organizing tool for governments to allocate expenditures that impact decarbonization. Most of the relevant activities—from innovation to diffusion of solutions through trade and foreign assistance—are parts of the connected process of technology development and deployment, or the "technology chain," and the public sector is involved throughout. Yet rarely in climate policy circles is the clean technology value chain seen as an integrated whole, with an acknowledgement that environmental and financial benefits of investments are shared globally.

This report suggests an approach that allows governments to take a more holistic view of their relevant expenditures. It will help policymakers and budget officers understand their place in the broader process, revealing where and how spillovers and learning feedbacks accrue throughout the technology chain, and allow governments to be more proactive in coordinating across traditional silos. In particular, the report deconstructs the variables and processes that underpin technology transitions, highlighting why a new approach is overdue to accelerate outcomes and save costs.

Not all investments have the same potential for realizing outcomes. Ideally, public investment in low-carbon technologies would have a positive correlation with decarbonization outcomes—more investment would yield more technological progress and market uptake of clean solutions. In reality, a number of contextual factors and nonlinear feedbacks along the technology chain influence the amount of decarbonization attributable to a given investment. With myriad investment options and ever-changing variables, countries face an unbounded puzzle in confronting decarbonization. Fragmented efforts and a narrow approach overlook that externalities and other actors continuously alter the collective investment horizon.

We can learn to do better. Policymakers are capable of working together among and between governments in service of a shared goal, adding global decarbonization to human spaceflight and decoding the human genome in the pantheon of modern accomplishments. We call on governments to take stock of their relevant expenditures and to develop a holistic approach to applying those expenditures to decarbonization. We likewise urge international initiatives to encourage and coordinate further study and elaboration of holistic approaches. Governments and relevant organizations can convene to further develop heuristics, explore variables, and define country priorities.

The global negotiations culminating in the Paris Agreement always emphasized the importance of public finance; now is the moment to make it an effective tool for driving outcomes. For those who live the daily realities of public policy and budgeting, the task may seem daunting: breaking down interagency silos, changing budgeting practices, and improving international coordination pose significant practical challenges. But the fact remains: we have a single decade to set the world on a significantly faster course to net zero, and the perfect does not need to be the enemy of the good in improving our flawed system. Governments are stewards of some of the most precious resources available in the fight against climate change, and we call on them to reimagine their role in this critical decade.

1 Introduction

Introduction

To say that finance is important for a livable future is stating the obvious, but it cannot be overstated. In 2010, then-Executive Secretary of the UN Framework Convention on Climate Change (UNFCCC) Christiana Figueres called finance “the golden key to real and tangible climate change action across the globe.”[1] Figueres was referring to the power of public finance to unlock the international climate negotiations, but the analogy holds as action grows more urgent. With time running out to set the world on a low-carbon trajectory and avert the most dangerous impacts of climate change, the choices we make in the coming decade will be decisive.

Achieving net-zero targets will require rapid and far-reaching change across the global economy, including overhauling entire energy, mobility, and industrial systems. We will need to bring diverse zero-carbon technologies to market in all sectors and countries, and we will need to develop the infrastructure and institutions to enable, accelerate, and sustain the transition. Technological change as a driver of decarbonization cannot be isolated from social and political processes: technological change can increase the social desirability and political feasibility of policy changes that are critical to rapid decarbonization. The policies available when solar power is several times more expensive than natural gas are different than when they are similar prices.[2] This report is therefore rooted not in optimism about the role of technology alone, but in the optimism that innovation-focused public policy can unlock technological, social, and political change.

This level of complex systems-change will require a concerted and comprehensive effort, including bold and rapid advances across political, economic, and social systems—and the means to finance the transition. Meanwhile, the international crisis of COVID-19 has upended and contracted global economies, rendering markets distressed and uncertain at a moment when bold and focused advances are critical. The scale of the challenge is both daunting and unprecedented. We need to act swiftly and strategically by harnessing the most powerful tools at our disposal—and public finance is one of the most valuable resources that society can apply to the challenge.

Throughout this report, we use a broad definition of public finance, including budget expenditures in the form of domestic spending and foreign assistance as well as fiscal policy tools like taxes and incentives. This report is intended primarily for policymakers in national governments, but it may also be of interest to climate finance and budget experts and for subnational governments. While we think the report is relevant for all countries (especially the activities described in Section 6), those most involved in clean technology development and deployment may play a larger role in implementation. We think our proposals apply to all sectors, although land use may require a tailored approach. Finally, we recognize that a livable future that achieves the goals of the Paris Agreement will require climate adaptation and will have to meet other sustainable development needs, but we discuss only decarbonization here.

Why Optimize Public Finance?

Public finance is but one of many levers that governments have to advance decarbonization (in addition to regulations, capacity-building, education, etc.), but it plays a uniquely critical and versatile role in driving global progress toward net-zero goals. Ultimately, decarbonizing the global economy will mean replacing or adapting the high-emitting assets that provide essential services with low-carbon alternatives—and developing and deploying the technologies to make that happen. Public finance is involved throughout these processes, including by de-risking innovation, fostering markets to support deployment, and sending market-shaping signals that leverage private-sector investment at all stages of technology development. While private actors may hesitate to invest in early stage innovation because of long payback times or uncertain profits, these risks are more tolerable for public finance. Governments can "make choices without picking winners," steering the direction and pace of change, creating markets that shift the innovation landscape toward certain societal goals by making it more profitable or easier for others to follow suit.[3]

Though powerful, public finance has so far been unable to turn the key to unlock decarbonization. Government allocation of finance to advance the low-carbon transition has been haphazard, variously driven by political priorities, siloed processes, or overt focus on the "low-hanging fruit," all of which risk neglecting the highest-impact uses of limited public funds. Domestically and internationally, governments lack a cohesive approach to answer an obvious question: How do we prioritize spending taxpayers' marginal green dollar in service of global decarbonization?

BOX 1. COVID-19: An underlined role for public expenditure at a pivotal moment

In the context of escalating public spending and calls to "build back better," the role of public expenditure is more important than ever. Government stimulus in response to COVID-19 is of such magnitude that it is rewiring global economies and significantly increasing the portion of economic demand coming from the public sector. At the same time, governments are, out of necessity, taking ownership stakes in major industries that supply goods and services to the economy. Consequently, public expenditure now has an even more decisive role in steering economic development and shaping global markets. Expenditure decisions that governments make through these stimulus investments will reverberate for decades to come, potentially making the difference between whether 2050 climate goals are achievable or not.

The weight of the moment has not been lost on the world. Experts have been quick to provide guidance for how countries should green their stimulus packages. The European Union is moving ahead with an enormous stimulus effort, nearly one-third of which is for green endeavors in which member states pledge to do no harm on climate.[4] But outside the EU, there is little coordination to ensure efforts across countries are aligned, mutually reinforcing, and capable of driving the necessary outcomes. At this elevated moment for public finance, how can we make it more efficient and effective, be more deliberate about the way we allocate scarce resources, and realize net-zero economies in time?

An Opportunity—and an Imperative—to Do Better

Not all investments in decarbonization have the same potential to drive outcomes, and identifying the investments that will make the most of limited resources requires a more holistic and deliberate approach. With time running out, we need to make better-informed decisions about how to spend scarce public resources for accelerated decarbonization. In this report, we will try to lift the lid on the "black box" that obscures whether a given investment will drive emissions reductions in the real economy. We aim to elucidate why the current approach to funding decarbonization is not working and offer ways forward for adopting a more holistic approach in practice.

We see an opportunity for public finance to do better but are cognizant of the challenges of reforming policy systems or budget processes. Even in countries where decarbonization is a political priority, we understand that governments always care about a suite of issues other than decarbonization. And while our message is relevant to all policymakers, we recognize that it is particularly important to budget officials, who have rarely been called upon directly as changemakers in the fight to decarbonize our economies. The motivation of this report is to illuminate how policymakers engaged in aspects of decarbonization can be more effective at their jobs and in turn, can help pave the way for economies to realize net-zero goals.

We do not need to be perfect to do better. There is immense, untapped potential to do more with public finance by steering market momentum more decisively toward decarbonization and fostering the necessary conditions for harnessing the self-organizing properties of markets to progress toward a new normal. Not only can optimizing expenditures deliver benefit for policymakers and global economies alike, but there is a global imperative to improve. The prospect of a better way forward is worth exploring.

In this report, we will first examine the process of technology development and deployment as a means to understand shortcomings of current public spending for driving decarbonization. We will then deconstruct the variables and processes that underpin technology transitions, highlighting why a new approach is needed to accelerate outcomes and save costs. Finally, we will discuss steps the international community can take to move toward a more holistic approach.

2 Accelerating Decarbonization through the Technology Chain

Accelerating Decarbonization through the Technology Chain

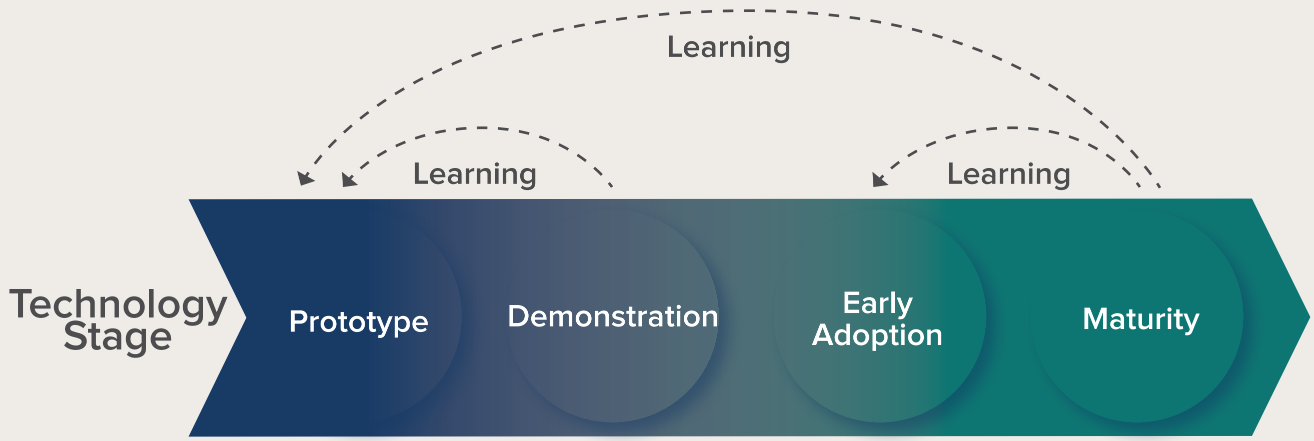
If a core piece of our collective challenge is indeed replacing today's high-emitting assets with low-carbon alternatives, then much of our work lies in developing and deploying the technologies for these alternatives. The power sector already provides one success story for how technological change can accelerate decarbonization. Clean energy technologies such as solar and wind are rapidly undercutting the cost of fossil fuels, not only displacing new pipelines of traditional fossil fuel plants, but also beginning to threaten the viability of *existing* plants and industries.[5] In other sectors, like industrial processes, we have many of the technologies we need, but they require support to achieve widespread adoption. And in some cases, we are still researching and developing solutions.[6] Bringing the full suite of solutions to market in all sectors and fostering tipping points to enable their widespread adoption will be critical to global decarbonization.

Following basic and applied research, a new technology goes through several stages of development and deployment on its way to widespread adoption. Here we refer to this process as the "technology chain" (Exhibit 1).[i] Different sources of finance have different roles in the process, and public finance, with some tolerance for uncertainty and longer-term investment outlook compared to the private sector, is involved in nearly every stage. Governments provide "resource-push" support in early stages to advance science and understanding and "market-pull" interventions later to improve market conditions and encourage adoption. Governments also provide foreign assistance to promote developing economies' access to technology solutions in a way that is tailored to their needs.[7]

[i] Often called the "innovation chain," here we use "technology chain" to indicate inclusion of the entire process of technology development and deployment, not just early-stage innovation.

EXHIBIT 1

The Technology Chain and the Role of Public Expenditures



	Prototype	Demonstration	Early Adoption	Maturity
Role of Public Expenditures	• Sets priorities • Stimulates activity in technologies that lack commercial value	• Reduces risk for investors and innovators • Provides concessional finance	• Levels the playing field • Creates niche markets to support scale-up	• Fosters market conditions that allow widespread adoption • Supports international uptake
Examples	• France-Germany collaborative support for basic research on smart grids and renewable energy storage • US ARPA-E funding to translate scientific discoveries into energy technology innovations	• Sweden's public-private partnership HYBRIT for fossil-free iron and steel • China's multi-year grants for state-owned enterprises to demonstrate priority energy technology challenges	• India's public procurement of LEDs, appliances, and electric vehicles • Germany's feed-in tariff for solar	• Investments in complementary infrastructure like EV charging • Foreign assistance or foreign direct investment for adoption in new markets

Source: RMI (adapted from the International Energy Agency).[8]

In practice, the path technologies take to deployment is rarely as linear as stylized depictions. To achieve widespread adoption, a new technology must become cost competitive with and replace existing technologies (or provide an affordable new service). This entails stages of nonlinear cost reductions and involves significant feedback across the technology chain, where knowledge gained from experience in one stage feeds back to improve design, production, or deployment processes.[9] This feedback has a spillover effect, also known as learning (shown as arrows in Exhibit 1), which reduces technology costs into the future and across sectors, technologies, and geographies.[10]

Meanwhile, investment in a technology's development and deployment is accompanied by the creation of complementary and supporting institutions, infrastructure, behaviors, and policies that cement its market position. This externality is known as "lock-in," a reinforcing feedback loop that results in increasing returns to scale and path-dependent outcomes.[11] Clean technologies will have to overcome the current carbon lock-in that perpetuates the use of fossil-fuel based technologies; as clean technologies are adopted, lock-in effects like the use of complementary clean infrastructure will engender momentum, making continued uptake of clean solutions increasingly easier.[12]

The forces of learning and lock-in underline the value of focusing on technology as we explore how to finance decarbonization; our ability to leverage learning and move from carbon to clean lock-in will shape the speed and total cost of global decarbonization. Technological change is just one element of the vast economic, social, and behavioral changes required for full decarbonization, but it is an important one. If we do not harness the processes (learning and lock-in) that connect the stages, we are missing opportunities to drive decarbonization quickly enough, and at least cost.

3 Challenging the Investment Orthodoxy

Challenging the Investment Orthodoxy

The idea of the technology chain discussed above is not novel. Why then are we failing to drive sufficient technologies toward widespread adoption? Institutions and decision-making tools are simply not built to approach expenditures holistically. We recognize that budgeting is a complex, often-politicized process. Governments know that evaluation tools and conventions are often faulty, but they are the best available in the absence of omniscience. Even governments committed to decarbonization have to balance priorities like job creation and industrial development.

In this section, we explore four ways that common budgetary processes undermine the goal of optimizing public finance for decarbonization. By shedding light on the deficiencies of the current paradigm, we introduce the possibility that governments could approach budgeting differently. We first discuss how decision-making approaches fail to address the complexities of the technology chain. We then look at how domestic and international structures slow potential decarbonization and finally, how international incentives miss important elements of decarbonization.

Decision-Making Approaches Are Overly Narrow

Public investment decisions reflect many inputs, including policy priorities like national security, economic growth, and job creation, as well as guidelines like responsible use of taxpayer funds and, of course, political considerations. But many tools for analyzing possible mitigation actions do not capture the full or accurate outcomes of investments in decarbonization.

Analyses can help policymakers answer the question of how they can reduce some emissions soon, but they do not help policymakers choose how to maximize long-term decarbonization at the lowest cost. Suboptimal investment decisions lead to long-term inefficiencies in two ways. First, they delay bringing needed technologies to market in sectors where decarbonization remains challenging (e.g., technologies for low-carbon steel and iron processes or electric vehicle infrastructure). Second, they introduce the risk of more expensive transitions, including the need for drastic interventions and abrupt transitions, such as from adjustment costs (e.g., from limited skilled workers or components); macroeconomic shocks related to sudden changes in energy use and price changes; or the abrupt revaluation of carbon-intensive assets before the end of their useful lives.[13]

Focusing on economy-wide decarbonization can lower the total cost of decarbonization, even though it may front-load those costs. First, an economy-wide perspective can drive positive spillover effects and cost reductions for nascent but promising solutions. Second, an economy-wide focus is needed for progress in sectors where abatement is harder and solutions take time to deploy. Finally, we need to look beyond boosting clean activities to ending dirty ones.

While scaling up green flows is crucial, it only reflects progress at the margins of the global economy compared with investment in fossil fuels. Further, carbon-intensive assets have long operational and economic lifetimes and a network of policies and infrastructure to support them; achieving mid-century

BOX 2. Overturning least-cost logic

Marginal abatement cost curves (MACCs) are a common policy tool to prioritize funding for abatement activities with the lowest marginal costs over the project lifetime.[14] Investing in the "low-hanging fruit" might be a prudent investment strategy in some circumstances, but it ignores technologies with high abatement potential that are costly today but that may be needed or become more competitive in the future. This was the case during the United States renewable energy certificate trading schemes that generally favored wind and biomass projects that were lower cost at the time, despite solar becoming the cheapest technology in the long run.[15]

Another set of tools to identify mitigation options is "integrated assessment models" (IAMs), which determine least-cost decarbonization pathways. MACCs and IAMs are important—we need to understand both mitigation costs and potential costs of climate impacts to address decarbonization. But these tools are based on simplified views of how technology costs have changed historically, rendering them ineffective for identifying investments in new or emerging clean technologies, and putting economies at risk of locking into investments that become uneconomical or inefficient over the long term.[16]

For example, personal vehicles have been the dominant mode of transportation in most of the world for decades, but demand is changing sharply with the rise of Mobility-as-a-Service and electric and autonomous vehicles.[17] It would be inaccurate and wasteful to plan subsidies for vehicles—both electric and gas powered—based only on past and current demand rather than on how these incentives will change demand over time.

decarbonization may be impossible without strategies to accelerate the retirement and turnover of today's carbon-intensive capital stock.[18] Separately, the cost of capital stock turnover will vary over time because the value of investment in a clean alternative comes both from avoided emissions and also from the value of the clean capital stock in the future. This suggests we should prioritize expensive investments or sectors with the highest abatement potential—an approach at odds with the least-cost convention.[19]

By failing to take steps to bring down costs of urgently needed technologies or retire the existing stock of high-emitting assets, least-cost investment logic and short-term prioritization uphold fossil fuel production, slowing progress and introducing excessive costs over time. Meanwhile, the total cost economies will have to bear increases with the amount of adaptation needed to respond to climate impacts, including sea level rise, drought, food insecurity, and the attendant economic and social impacts—a cost that is already rising.[20]

Domestically, Budget Processes Are Siloed and Hindered by Politics

Governments enact their budgets through a variety of fiscal and financial tools, which in turn support a range of incentives and programs. Exhibit 2 is a non-exhaustive list of tools showing the breadth of ways public expenditure affects decarbonization. The structure and process of government budgeting often lead to remarkably siloed decision-making, even when activities may have related outcomes. Even if we look only at the parts of a national budget related to decarbonization, these expenditures occur across the economy, and some are at cross-purposes.

EXHIBIT 2
Public Expenditures Accelerate or Impede Decarbonization

	Actions that ACCELERATE outcomes	Actions that IMPEDE outcomes
TAXES AND RAISING CAPITAL Tools to increase government resources	• Carbon taxes • Green bond issuance	• Fossil fuel extraction on public lands • Import tariffs on low-carbon technologies
TAX BREAKS Foregone revenue	• Production tax credits (PTCs) and investment tax credits (ITCs) for low-carbon energy	• Tax exemptions and deductions for oil and gas • Favorable tax depreciation for fossil fuel assets
INCENTIVES Subsidies and price-support controls to spur investment	• Solar feed-in tariffs • Renewable certificates	• Fossil fuel subsidies
INVESTMENTS Direct budget allocations	• Low-carbon research, development, and demonstration • Public procurement • Workforce transition programs	• Fossil fuel infrastructure investment
INSTITUTIONAL SUPPORT Allocations to public financial institutions and funds	• Capitalization to green banks • Contributions to multilateral climate funds	• Contributions to multilateral development banks for fossil infrastructure

For example, spending for different parts of the technology chain may be directed separately. One part of an agency may be responsible for renewable energy research, development, and demonstration (RD&D), while another implements deployment programs, and a third coordinates development assistance. Further, when governments track their "climate finance" spending for the UNFCCC, they look primarily at international efforts (foreign assistance, foreign direct investment) without considering the many domestic activities that advance decarbonization globally.

We can understand why someone working in foreign assistance would not pay much attention to domestic subsidies. While a government budgeting entity (like the US Office of Management and Budget) coordinates and oversees these various expenditures, in practice, siloing remains, and policy (or political) trade-offs exist. Different external stakeholders and lobbying groups influence budgetary decisions in isolation, different legislative committees shape outcomes, and different ministers and bureaucrats have discretion within their allocations. As the saying goes, where you stand depends on where you sit.

Working in isolation, policymakers are trying to make budget decisions from fragmented perspectives of RD&D, deployment, development assistance, and so on, making it nearly impossible to know if they have made expenditure decisions that support or are supported by their colleagues' efforts. If governments instead consider the opportunities offered by different stages of the technology chain—including renewable energy, infrastructure, industrial activities, fossil fuel subsidies, and international climate finance—for meeting the same objective, then they could be in a better position to plan their expenditures to maximize decarbonization.

It would be naïve to think the prospect of maximizing decarbonization is enough to overcome entrenched bureaucracy and competing policy priorities—not to mention business and lobbying interests, political capture, and corruption. Moving to an integrated approach is a tall order. But recognizing the ways in which current working modes slow decarbonization is an important early step in thinking about how to make more effective and efficient spending decisions.

Internationally, Investment Decisions Are Fragmented and Insular

A country fully committed to decarbonization would face a steep challenge in a solo effort to push new technologies to their global tipping points. Even several countries taking this approach in isolation are unlikely to enable widespread global adoption of the full set of solutions soon enough. It follows that policymakers looking to decarbonize should pay keen attention to international cooperation—but often they do not. In the United States there has been excitement in many quarters about the Green New Deal proposal, the broad aim of which is to achieve the total decarbonization of economic sectors in as little as 10 years. Yet the proposal places little emphasis on the potential and need to drive progress internationally.

In effect, the siloing that hinders domestic decision-making extends to international investments as well. Government officials involved in foreign direct investment, development aid, multilateral bodies, and plurilateral initiatives often are not well integrated with their counterparts working on clean technologies. Decisions about both domestic and international climate spending are thus often made without understanding how other countries are investing in the same, competing, or complementary technologies—or the global potential for technology adoption.

The past decade has seen a proliferation of international cooperative efforts as countries have ramped up climate action. Relevant initiatives exist to support key areas of cooperation for global decarbonization—technology innovation, technology deployment, and scaling down finance for fossil fuels (Box 3), but these initiatives largely work separately. When efforts related to different parts

BOX 3. Relevant international cooperative initiatives

- **Innovation:** Launched just before the Paris Agreement was finalized, Mission Innovation was founded to scale up public investment for clean energy innovation. While much of this work will happen domestically, Mission Innovation also fosters partnerships between members (representing over 80% of global clean energy RD&D budgets) and encourages private sector investment

- **Deployment:** The Clean Energy Ministerial (CEM) is a high-level forum to advance clean energy technology. The CEM's 26 members account for about 90% of global clean energy investments.[21]

- **Heavy industry:** The World Economic Forum's Mission Possible Platform is a coalition of governments, private industry, and experts "working on creating tipping points across the hard-to-abate sectors…through public-private collaboration, innovation partnerships, and industry alliances."[22]

- **Fossil fuel subsidies:** For countries seeking to decrease investments in fossil fuel generation or phase out subsidies for fossil fuels (including those countries that pledged to do so in the Group of 20 or Asia-Pacific Economic Cooperation), there is not a singular forum for cooperation, and there is little ongoing technical cooperation in the G20 or APEC. Friends of Fossil Fuel Subsidy Reform for non-G20 and APEC countries is more active but excludes many major economies.

- **Asset retirement:** The Powering Past Coal Alliance has received strong interest from national and subnational governments, businesses, and other organizations committed to the goal of ending coal power generation. This is a promising venue to share best practices on financing coal phaseout, but some key coal-dependent countries are absent.

of the technology chain are not coordinated, potential "valleys of death" are more acute, for example when global markets for uptake of a new demonstrated technology are insufficient. Fragmentation between initiatives also makes the landscape difficult to navigate and dilutes collective efforts, and the prevailing view is that more coordination is needed, at least on innovation and deployment.[23]

International Incentives Are Narrowly Defined

One of the central concepts of climate finance as enshrined in the UNFCCC, and therefore the Paris Agreement, is the notion of incremental cost. Assuming the green option was more expensive than the dirty incumbent meant there would be an incremental cost for the adoption of green technologies, and someone would have to bear that cost, particularly if it was higher in a developing country context. Thus, one of the responsibilities of developed countries under the UNFCCC became covering this incremental cost for developing countries. Yes, the green option was more expensive when the UNFCCC was established in 1992, but that is no longer true for key activities like power generation, where clean energy is now cheaper in most markets than coal or even gas. In large part this is due to public investment along the technology chain.[24]

Yet incremental cost logic still underpins the way commitments are framed in the UNFCCC and therefore continues to shape decisions by national governments. Specifically, in 2009, developed countries committed to mobilize $100 billion per year by 2020 from public and private sources to support climate mitigation and adaptation in developing countries. Progress on climate finance has therefore been measured by the somewhat narrow metric of how much low-carbon investment provided or facilitated by public institutions is flowing each year from the global North to South. By that metric, finance for climate activities has increased in recent years, and finance for mitigation is over 90% of those flows.[25] Yet this volumetric approach creates incentive to simply increase quantities of spending, rather than to deliver results per se or pursue retirement of existing dirty infrastructure responsible for emissions.[26]

The logic of incremental cost leaves policymakers without an incentive to design spending programs that target long-term investment at all stages of technology development. Countries only get international political recognition when they provide climate finance—narrowly bounded in the UNFCCC—to developing countries bilaterally or via a multilateral institution. But this support only addresses a fraction of the challenge. Comparable climate benefits can be delivered through domestic investments that disrupt high-carbon incumbents (e.g., through securitization or accelerated depreciation to retire the dirty stock), or those that will make an early stage technology globally affordable. An ecosystem of support across all stages of technology development and deployment is needed to pave the way for the ultimate adoption of clean technologies. So why are we only incentivizing contributions to one piece of the challenge?

Another issue of significance to our exploration is technology development and transfer. In the fractious UNFCCC negotiations, some developing countries insist all intellectual property be made globally available and free. While private companies that hold patents for decarbonization technologies may choose not to do business in some countries, many relevant patents are indeed publicly available. In the same way the financial mobilization target distracts from the desired outcome of actual climate action, the focus on intellectual property rights in isolation distracts from the reality that many countries have trouble adopting these technologies—or developing their own—because of inadequate enabling environments (related to, for example, technical capacity, regulatory environment, or capital markets).

Exploring evolution of the intellectual property regime to maximize both the incentive for innovation and the rate of technological diffusion for public benefit is important, but readying all countries for the global energy transition is likely a higher-impact goal than free access to intellectual property. The technology framework called for in the Paris Agreement shifts the focus by balancing its work among innovation, implementation of climate technologies, enabling environment and capacity-building, collaboration and stakeholder development, and support that is “broader than just financial support.”[27]

4 Unlocking the Black Box of Investments in Decarbonization

Unlocking the Black Box of Investments in Decarbonization

Section 3 described how certain aspects of public finance lead to material inefficiencies for financing decarbonization. As a result, the overall impact of many national budgets is to slow or deter, rather than accelerate, global decarbonization. We have seen that public finance can play an important role throughout the technology chain, but to realize economy-wide decarbonization in time, we need more successes from public finance more quickly. To change the outcome, we must change the approach.

We have a substantial understanding of what the collective decarbonization challenge entails. Decarbonization pathways illustrate how global economies can reduce emissions over time based on a range of approaches and technologies across sectors, and initiatives like the International Energy Agency's (IEA's) Tracking Clean Energy Progress assess innovation gaps for low-carbon technologies.[28] But there are many possible pathways—the Intergovernmental Panel on Climate Change's latest assessment report describes 90 possible mitigation pathways aligned with a below 1.5°C world and an additional 132 consistent with a 2°C trajectory.[29] For an individual policymaker or budget officer, there remain endless combinations of investments that could contribute to progress toward these goals at different total costs.

While some investments are more promising than others, it would be unworkable for a policymaker to pinpoint the fastest and most affordable path because energy and industrial systems are both complex and adaptive.[30] The relationships and feedbacks that determine whether a given investment will deliver meaningful impact are constantly emerging, evolving, and nearly impossible to quantify with any precision. But complexity cannot be the excuse for falling back to ineffective investment. Rather, it should serve as evidence that a new approach for making investment decisions is needed.

Inside the "Black Box"

The process by which an investment of public funds becomes a measurable emissions outcome entails a multitude of factors interacting to turn input into output. This process is a "black box" in that the complexity of the interactions makes it difficult to determine the output: how much decarbonization will result and how cost-effective the investment will be. In the rest of this section, we try to pull back the lid on this black box to give policymakers a sense of the factors at work and how they interact.

Primarily, the black box is intended as a heuristic to demonstrate the value of a more holistic approach by helping make sense of the conditions and processes that impact the success of investments for driving outcomes. Rather than offering a failsafe means for policymakers to solve for investments that are guaranteed to drive decarbonization, the black box should convey the system's inherent uncertainty, serving as evidence that a new approach is needed to manage the risk and complexity.

Exhibit 3 is a visualization of the black box depicting a single investment from one actor in a low-carbon technology. Inside the black box, variable circumstances ("**multipliers**") change an investment's decarbonization potential. These multipliers help determine the technology's **progress along the technology chain**, with amplified or reduced progress accruing based on the multiplier values. As technologies develop, feedback from cost reductions and market uptake influences the values of multipliers for future investments. The combined interaction of the multipliers, feedback, technological progress over time, and **investments by other countries and private actors** in the same technology transform the initial investment into the output of the black box: the "**decarbonization impact of investment**," or the emissions reductions attributable to the investment over time. We explore these elements in detail below.

MULTIPLIERS: Specific Circumstances Determine Investment Impact

In theory, the amount of public investment in low-carbon technologies should have a positive correlation with decarbonization—more dollars invested, more technological progress and market uptake of clean solutions. In reality, the relationship is not as straightforward, and the amount of decarbonization ultimately attributable to a given investment varies based on a number of factors. Here, we attribute the differences in decarbonization outcomes to multipliers related to country context and technology factors (Exhibits 4 and 5). Country multipliers reflect innate or slow-changing characteristics of the country making the investment, such as the strength of their innovation ecosystem or the existence of compatible infrastructure to enable uptake of emerging technologies. Technology multipliers are based on how expensive or risky the technology is and how quickly its costs can change over time from different kinds of investments.

Take, for example, how investment in a technology's development and deployment is accompanied by lock-in via the creation of complementary and supporting institutions, infrastructure, behaviors, and policies that cement its market position. Lock-in can be leveraged to promote a *virtuous* cycle, whereby learning feedbacks and network effects (e.g., establishing supporting infrastructure to encourage deployment) help realize tipping points for low-carbon technologies, and market forces drive continued cost reductions, removal of barriers to adoption, and exponential uptake at lower cost.[31] Investments that seek to establish and capitalize on these processes and conditions can have an outsized positive impact for driving outcomes.

Conversely, for countries experiencing strong carbon lock-in, diffusion of low-carbon alternatives will require disrupting the status quo, such that investing in domestic, clean technology deployment may achieve *less* decarbonization in the near term or on a per dollar basis without, for instance, simultaneous investment to dismantle fossil fuel infrastructure. Countries might exhibit characteristics that either fully or partially cancel out across multipliers.

For country multipliers, we make the distinction between competitive advantage in "innovation" and "manufacturing" to illustrate that a country's advantages may vary across the technology chain. This is intended to be illustrative, and we recognize the technology chain is more fluid and nuanced. The country multipliers also assume that expenditures will be invested domestically. In the case of international dissemination, these same factors could be applied to evaluate the country where funds will be spent.

EXHIBIT 3

Inside the Black Box: How Multipliers Influence Decarbonization

From Investment to Impact

The black box helps us visualize the dynamic and cyclical forces that act on an investment to determine its decarbonization impact. An investment entering the black box has its impact amplified or reduced by variables ("multipliers") inside the black box. The figure shows the multipliers as different sizes to represent how they amplify or reduce the impact of an investment. The product of the investment (input) times the multipliers is the decarbonization impact of investment (output). Outside the box, progress along the technology chain and spillovers from outside investments by other countries and the private sector feed back into the box for future investments.

Country Multipliers

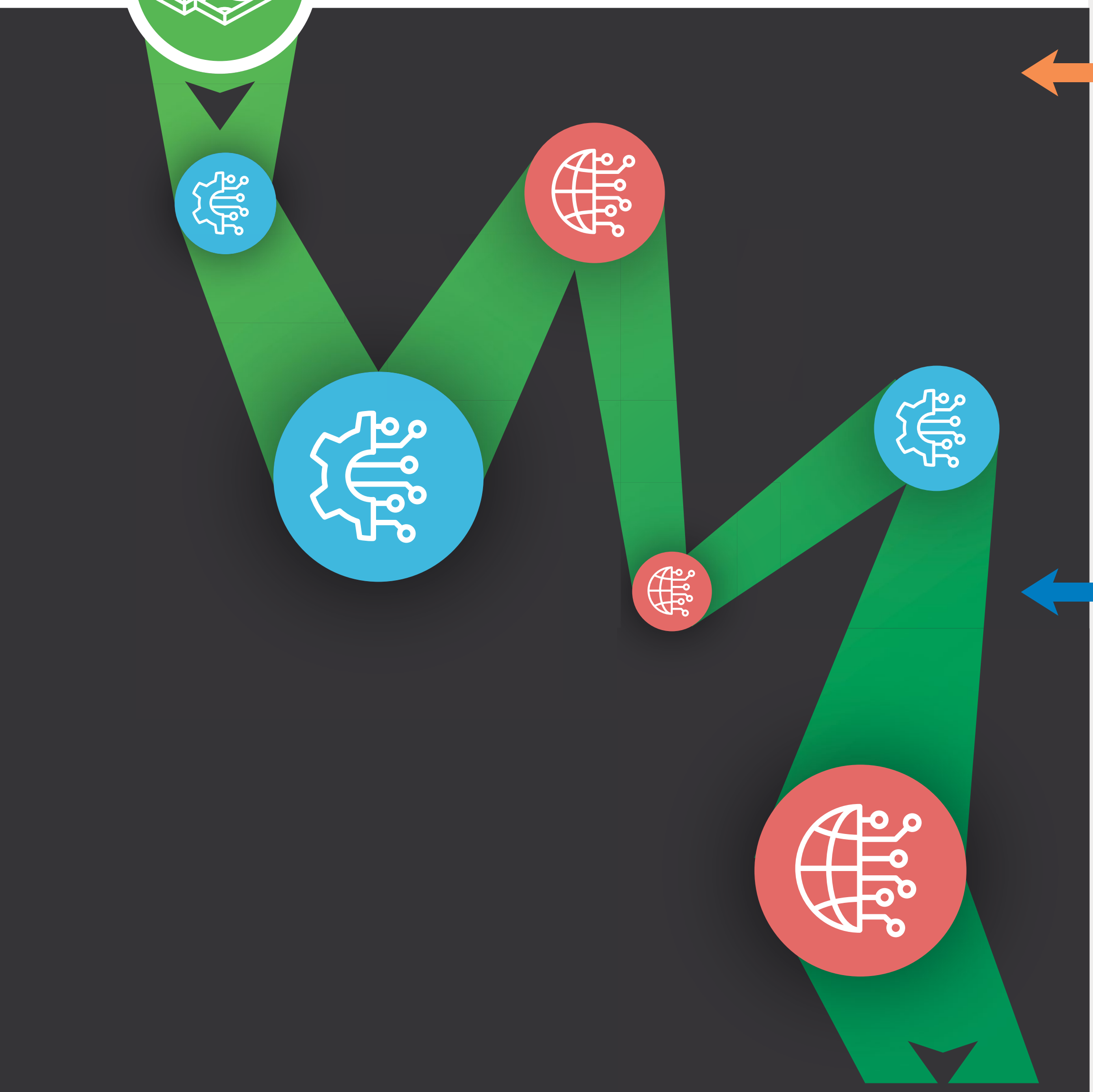
- Carbon lock-In
- Carbon trajectory
- Enabling environment
- Competitive advantage (innovation)
- Competitive advantage (manufacturing)

Technology Multipliers

- Learning potential
- Carbon trajectory
- Risk outlook
- Economies of scale potential
- Complementary infrastructure

Investment

The process by which an investment in decarbonization becomes a measurable reduction in emissions entails a multitude of factors interacting to turn the investment value into an output.



Investments by other countries and private actors also affect technology progress through spillovers.

Progress along the technology chain feeds back into the box, changing the value of the multipliers for future investments.

Decarbonization Impact of Investment

The investment ultimately results in emissions reductions over time. The magnitude of those reductions depends on the nature of the interactions in the black box.

The decarbonization impact of investment drives progress along the technology chain.

EXHIBIT 4

Country Multipliers: Country Characteristics Influence Investment Potential[ii]

Multiplier	Description	Relationship with decarbonization progress
Strong competitive advantage in early innovation	Relative demonstrated RD&D capacity based on funding, institutions, innovation culture, loan practices and terms, etc.	**Positive multiplier for upstream investment:** Countries with high RD&D capacity and innovation ecosystems (including strong private sector or venture capital interest) are more likely to efficiently advance technologies along early stages of technology development through "resource-push" incentives, including investment in upstream RD&D for prototype technologies
Strong competitive advantage in manufacturing	Relative demonstrated manufacturing efficiency, based on processes, institutions, engineering capacity, etc.	**Positive multiplier for downstream investment:** Countries with high manufacturing capacity are more likely to efficiently advance technologies along later stages of technology development through "market-pull" incentives such as fostering niche markets or leveling markets for deployment and commercialization
Strong carbon lock-in	Degree to which fossil fuel use is engrained through national infrastructure, institutions, or policies and regulation	**Negative multiplier for deployment investment:** Lock-in leads to increasing returns to scale and path-dependent outcomes that perpetuate fossil fuel use even as lower-cost, cleaner alternatives become available[32]
High-carbon trajectory	Degree of projected carbon lock-in based on national energy demand projections	**Positive multiplier for deployment investment:** Low-carbon progress in countries on high-carbon trajectories is important to avoid (rather than displace) high-emitting assets and mitigate potential lock-in
Strong enabling environment	Ability to efficiently uptake low-carbon solutions based on institutional readiness, complementary infrastructure and technical capability, political will, aligned regulations and incentives	**Positive correlation with investments:** A country's political economy, budget size, regulatory context, and physical environment can facilitate (or inhibit) efficient uptake of emerging solutions

[ii] The variables and multipliers explored in the rest of this section and Exhibit 3 are intended to be illustrative and non-exhaustive. We recognize we have defined the variables in a way that may introduce double counting.

EXHIBIT 5

Technology Multipliers: Technology Characteristics Influence Investment Potential

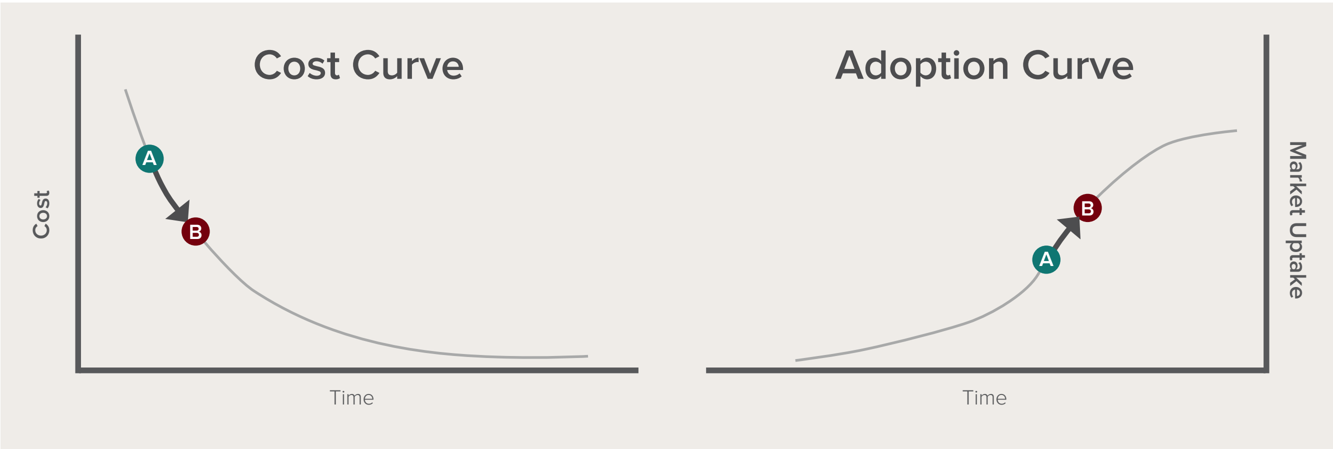
Multiplier	Description	Relationship with decarbonization progress
High learning potential	Magnitude of a technology's cost reductions from every doubling of cumulative experience	**Positive multiplier for investment:** Learning mechanisms are present to varying degrees across the technology chain and reduce technology costs into the future as experience accumulates[33]
High economies of scale potential	Magnitude of cost advantages due to fixed and variable costs increasing more slowly than the volume of output[34]	**Positive multiplier:** As production scales (including through creation of global markets), certain technologies benefit from lower costs per unit of production
High spillover potential	Magnitude of spillovers that are likely to result from learning processes	**Positive multiplier:** Spillovers can occur across technologies, industries, or geographies, creating tangible benefits beyond the direct scope
Strong network effects	Degree to which costs decrease as a technology diffuses, especially due to the availability of complementary infrastructure or technologies	**Positive multiplier for deployment investments:** As a technology becomes more prevalent, it becomes easier for others to adopt (e.g., EV uptake prompts deployment of charging infrastructure which further incentivizes late adopters to switch to EVs)
High-risk technology	Perceived risk associated with a technology progressing toward commercialization	**Negative multiplier for investment:** If successful, investment in early-stage technologies can generate significant positive impact for decarbonization globally, but this opportunity must be balanced with technical, market, and funding risks

PROGRESS ALONG THE TECHNOLOGY CHAIN: Feedback Drives Outcomes

Values for some multipliers depend on the stage of technology development, and vice versa, through a dynamic feedback process. As we saw in our discussion of learning, supporting technologies from early research to market deployment and dissemination along the technology chain is a fluid process, which can be represented by a pair of curves (Exhibit 6). The technology cost curve (sometimes called an experience or learning curve) reflects how a technology's cost decreases over time (from point A to point B) because of factors like knowledge accumulated from production-based learning. The adoption S-curve shows how a technology's market share increases over time (from point A to point B), with a steeper curve representing faster uptake.

EXHIBIT 6

Progress Along the Technology Chain Drives Cost Reductions and Market Uptake



Investments that harness strongly positive multipliers will more efficiently contribute to advancing solutions along these curves, and therefore along the technology chain, because the dollar value of the investment has been "multiplied" with respect to its impact. As a result, technologies experience cost reductions and uptake more quickly and at lower total cost. Progress along the technology chain, in turn, influences the value of the multipliers for future investment in that and other technologies, with spillovers accruing across sectors and countries.

INVESTMENTS BY OTHER COUNTRIES AND PRIVATE ACTORS: Streamlining Global Efforts

Another aspect of learning is the potential for spillovers. Maximizing learning as a means to optimizing global investment will require international cooperation because domestic investments push solutions along their country-specific cost and adoption curves, and these efforts may indirectly translate to cost reductions in other sectors, geographies, or technologies as learning spreads. Quantifying where in the world returns will accrue and in what quantity is difficult. Nonetheless, acknowledging that the value derived from many investments in decarbonization is shared globally would be a starting point for crafting improved policy and effective coalitions for action.

Further, because of the limited nature of public funds (and the size of the "investment gap"), it is a tenet of climate finance that public finance should seek to catalyze multiples of private investment. Governments can attract private investment at all stages of the technology chain, by engaging in market creation and market development and by providing long-term certainty through targets and incentives. Private finance will, in turn, influence the investment landscape by contributing to cost reductions and reinforcing global efforts to bring technologies to scale. Government incentives have long been used to crowd in private investment and amplify the impact of public dollars. But different government interventions can be more or less catalytic, and better understanding is needed for governments to understand which signals and incentives are strongest for driving their intended outcomes.

BOX 4. Solar photovoltaic cost reductions

The case of solar photovoltaics (PV) exemplifies how different countries investing along the technology chain encourage global benefits through cost reductions and knowledge gains. The United States made the earliest PV investments in the 1950s, and the technology was first used in space research. It was not until the oil shocks of the 1970s that both Japan and the United States increased public finance for PV to address energy security concerns. From there, government laboratories were spun off into private companies that identified niche applications for PV, further fostering its development.

Despite progress in these markets, PV for electricity remained largely cost prohibitive until the 1990s, when government procurement and incentive policies in Germany, Japan, and the United States facilitated scale-up. These successful examples prompted increased funding in PV R&D around the world, resulting in more patents and cost reductions. In particular, Germany implemented the first feed-in tariffs in the 1990s, and over the next two decades, China, India, Italy, Spain, and the United States followed suit with similar market-pull incentives. These incentives were reinforced by deployment targets and complementary grid infrastructure, providing the market certainty for global supply chains to take off.

As global markets flourished in Europe, Japan, and the United States, they attracted new entrants in solar PV manufacturing in China. At the time, although domestic deployment incentives for PV were weak, local governments offered attractive incentives, such as cheap loans, subsidized electricity prices, or tax incentives, to establish PV manufacturing facilities. Thanks to successful vertical integration and economies of scale, the growth of Chinese solar manufacturing—initially fueled by international demands—helped drive solar PV to cost competitiveness in many markets.[35] Although not an early investor in PV innovation, China has been the global leader in module manufacturing and installations over the past decade.

Cross-border spillovers, as well as the importance of country context, are evidenced by the different timelines for PV to reach maturity in different countries. It took Germany, an early mover in PV markets, nearly 20 years to achieve 1% of national electricity demand from solar PV after its first capacity addition around 1990. In the Philippines, where the first solar capacity was not recorded until 2005, the same level of market saturation was achieved in half the time. While the Philippines and other countries clearly benefited from international investment, which helped drive down the up-front cost of solar PV systems, some early investors also reaped benefits by becoming industry leaders. This was the case for some European companies that continue to specialize in solar PV manufacturing equipment and inverters. Technology spillovers also played an important role in the development of solar PV. In particular, knowledge accrued in silicon manufacturing for semiconductors likely facilitated initial solar PV developments in the 1970s and 1980s.

Case study adapted from the International Energy Agency[36]

Toward Better Outcomes

Decarbonization has been likened to a global, economy-wide puzzle. The analogy suggests that decarbonization progress is the sum of collective efforts to decarbonize and that our collective challenge simply requires devoting enough resources to figure out how to put the pieces together. But with myriad investment options to advance decarbonization and ever-changing variables, our challenge is not one of solving a puzzle with pieces that are well defined and predestined to fit together. Rather, the decarbonization puzzle is unbounded, and the contours are evolving in every direction as different actors intervene. By initiating cost reductions for low-carbon technologies, providing complementary infrastructure, or reinforcing market barriers, the success of every investment in decarbonization is inextricably linked to previous and subsequent investments in the system.

A more apt, albeit messier, analogy might be that every investment in decarbonization gives shape to a piece of the puzzle that redefines the contours of the outstanding challenge for everyone, either making it simpler or more difficult to solve. Yes, individual domestic actions can have international impact. But to work in isolation on the decarbonization puzzle would ignore the fact that decisions by others, including uncoordinated actions within a country, might render the impact of one actor's contributions redundant or ineffective.

Fragmented efforts and a narrow approach overlook that externalities, learning processes, and investments by other actors continuously alter the investment horizon, either improving or encumbering the efficacy of various investment options for driving decarbonization. An improved approach to allocating public finance would target opportunities to harness and capture the value of reinforcing processes or complementary efforts, amplifying positive impact while addressing or accounting for obstacles that might negate efforts.

BOX 5. Simulating more holistic decision-making

In preparation for this report, a group of climate finance and budget experts participated in an exercise based on the black box to simulate making expenditure decisions.[iii] The premise was that five fictional countries were planning stimulus packages with a policy mandate to prioritize decarbonization. Each participant played the role of a budget official (e.g., technology development budget officer or foreign assistance budget officer) advocating for a different type of expenditure for a given country. The goal was for each country to allocate funds across four low-carbon technologies—representing solutions from prototype to maturity—to maximize the "decarbonization impact of investment."

$$\text{decarbonization impact of investment} = \text{investment} \times \text{country multipliers} \times \text{technology multipliers}$$

Every country was assigned unique country multipliers. For instance, "carbon lock-in" multipliers indicated the degree to which a country was locked into fossil fuels, and therefore how difficult it might be for emerging low-carbon technologies to come online. The carbon lock-in multiplier was applied to investments in deployment, such that countries with low carbon lock-in realized more impact from deployment investments, and countries with high carbon lock-in realized less from those investments. Similarly, countries with a strong "competitive advantage in early innovation" were assigned a multiplier to generate more decarbonization impact from investments in nascent technologies.

Additionally, each technology had its own multipliers, which were the same for all countries. As a result, countries were forced to balance the realities of the innovation landscape with their unique circumstances. For instance, is it more beneficial for a country to invest in a technology with the highest multipliers, or would the realities of country-specific strengths, weaknesses, and barriers reduce the impact of investment in seemingly winning technologies?

For the simulation, each country decided how to distribute its investments across technologies. In contrast to the real world, officials from the same country could easily confer with each other. These decisions produced a different "decarbonization impact of investment" for each country. We then adjusted outputs to reflect the global nature of innovation systems. For instance, to simulate the reinforcing feedback of tipping points in the technology that received the most investment across countries, we applied a positive multiplier to the "decarbonization impact of investment" of all countries that invested in that technology. The goal was to highlight how an internationally coordinated approach can outweigh the value of well-intentioned and even domestically strategic investments by fragmented actors.

The simulation was highly simplified, but it provided a constructive opportunity to break down the traditional silos inherent in budget processes and observe how working together can drive more impact from investments. After engaging with the challenges firsthand, participants were better equipped with a shared framework to discuss the value of a new approach in practice, including what it might look like for different governments to implement, and some of the opportunities and barriers in doing so.

[iii] The simulation described is available for download with this report at **https://rmi.org/insight/recasting-the-golden-key**.

5 Toward Optimizing: A Holistic Approach

Toward Optimizing: A Holistic Approach

In a complex and constantly changing system, there is more than one path the global community could take based on available resources and country circumstances at a given time. We explored the technology chain and black box to illustrate why fragmented efforts and a narrow approach are unlikely to coalesce around the sort of mutually reinforcing momentum that is necessary to affect outcomes in time. Rather than individual actors gambling on specific routes forward, policymakers should strive to steer markets in the direction of pathways that might be less encumbered, faster, or mutually beneficial. Countries are not starting from scratch; there is significant scholarship that can be brought to bear on how to target support to maximize benefits. To work toward this goal, we propose policymakers explore these areas:

- Adopt an organizing principle to coordinate spending across a budget
- Leverage international complementarity through strategic, mission-driven coalitions
- Reform international political commitments and rewards to recognize outcomes

The following section will describe how striving to implement these improvements can enable and reinforce a more holistic approach in practice. Examples of existing best practices are highlighted throughout.

Domestically, Identify and Integrate Relevant Expenditures

We have seen how different government expenditures to support technology development and deployment are connected along the technology chain, and we have seen how governments are often not positioned to exploit this fact. Even where political will to achieve a policy priority exists, policymakers might not know the full scope of existing or potential spending that could support (or undermine) that priority. It is crucial for governments to know which of their expenditures relate to decarbonization so they can understand how they relate to each other. Budget officials can think about investment activities along the technology chain as one decarbonization portfolio consisting of technologies closer to or farther from the tipping points that will unleash development or deployment. Re-envisioning and refocusing single-point interventions across the budget as one strategically diversified and complementary set of solutions can help tackle systems progress. This approach can also help various policymakers understand their place in the process.

The technology chain is only one example of a heuristic that policymakers could use to organize relevant expenditures. Using the technology chain as a reference point should not imply that we only need techno-economic improvements to drive decarbonization. While the act of transitioning economies may at its core be a question of technological turnover, success depends on amenable social and political conditions to facilitate progress. Still, coordinating spending in this way can help reveal where and how spillovers and feedbacks accrue throughout the process of technology development and deployment, allowing governments to be more proactive and effective in capitalizing on these externalities.

Integrating relevant expenditures as one portfolio of activity could, for example, enable better comparison of the suitability of interventions along the technology chain. Despite a need for completely new technologies in some sectors, the necessary low-carbon solutions already exist for many other sectors, and in these cases, the highest-impact expenditures are demand-pull measures that bring existing solutions to cost parity. Additionally, integration can highlight the value of investments that may not independently merit consideration but will be critical to unlocking outcomes in combination with other investments, like complementary infrastructure. Finally, integrating budget practices can expose the contradictory and profligate relationship between expenditures for fossil fuels and renewables. Governments that allocate expenditures to both (including in the forms of legacy subsidies and tax breaks for fossil fuels) uphold market barriers to clean technologies coming online, undermining the decarbonization potential of their own budget and preserving fossil fuels' artificial competitive edge.

BOX 6. SunShot: Integrating expenditures based on the technology chain

How can governments looking to overcome siloing apply an organizing principle to unite expenditures, and what benefit would doing so bring? Past examples suggest that coordination along the technology chain can facilitate the kind of holistic and forward-looking investment needed to drive decarbonization at lower costs. In 2011, the US Department of Energy established the SunShot Initiative to make solar cost competitive without subsidies by reducing solar costs 75% by 2020. SunShot adopted an integrated approach of financial support along the technology chain (including early stage R&D for solar hardware), spending on grid challenges to facilitate deployment, and advancing innovative business models to mitigate market barriers and accelerate commercialization. Not only did SunShot meet its goal three years early, but it showed that integrating public investment along the technology chain can deliver real-world progress. As a result of the $282 million public investment in SunShot programs in 2015, there was a 97% increase in US photovoltaics installments by the next year, representing upward of $30 billion in deployed capital.[37]

Predicting which technologies will be most successful and where spillovers will occur is inherently difficult and uncertain. Integration need not require an "all eggs in one basket" approach to investing in certain technologies; integration simply allows policymakers to consider their options as part of a whole. A government using an integrated budgeting approach could decide to diversify its investments, seeking complementary and mutually reinforcing interventions over time.

Internationally, Leverage Coalitions

One can envision two international approaches to technologies for decarbonization: going "all in" on a few technologies or different countries each working on different technologies. Given the range of technologies we need and the short timeline, the reality is that we will likely need coordination among countries and other stakeholders to pursue both approaches. There are significant opportunities for countries to cooperate to push solutions along the technology chain, but tension also exists between cooperation and maintaining a competitive advantage as well as between the free transfer of technology and intellectual property rights. While there is no blueprint for tackling climate change, there have been various investment- and innovation-led approaches to solving societal challenges in other sectors, as well as ongoing and promising efforts on climate that demonstrate several success factors.

First, international cooperation should be guided by a well-defined "mission" to unite disparate actors with a shared vision for the necessary direction of change.[38] For instance, beginning in 2021, the European Commission's Horizon Europe program will allocate 100 billion euros across five strategically and clearly defined "research and innovation missions," including "100 Climate-Neutral Cities by 2030" and "Accelerating the Transition to a Climate Prepared and Resilient Europe."[39]

Setting a direction of change in this way creates links between traditionally fragmented but related activities and can steer action and investment allocation without prescribing outcomes, acknowledging that different policy approaches will work better in different country contexts and that different markets are better suited to support different technologies. One example is the Human Genome Project's goal of mapping the human genome, which set out a broad enough target to mobilize a large set of researchers but was specific and measurable, providing accountability and clarity with respect to desired outcomes. When resources or knowledge bases are complementary, a shared goal can be beneficial to promote regional competitiveness or to deliver a global public good. Here, the European Union's Smart Specialisation work, which helps member countries identify niche areas of competitive advantage for interregional growth around thematic platforms, could also offer lessons.[40]

Second, international cooperation should strive for a balance between centralized, small-group, and individual efforts. Small coalitions of countries interested in particular challenges and solutions may prove practical and nimble. History has shown that plurilateral efforts can move faster than global multilateralism; only a few countries may need to be involved at any stage of a given technology. At the same time, a centralized agenda can provide coordination to guide and monitor progress. For example, as part of Mission Innovation, 24 countries and the EU have committed to double clean energy R&D investments across eight priority areas, or "innovation challenges." Each country chooses how it wants to pursue each challenge and with whom, capitalizing on different strengths under a shared mission.[41]

Third, similar to the benefits of a portfolio of assets for a national budget, and given the inevitable failure of some innovations and the multifaceted nature of many "mission-oriented" challenges, a coalition of countries can manage coordination through a portfolio approach, leveraging diversity and distributing and hedging risk across nations.[42] A portfolio approach to cooperation can enable synergies through risk sharing, and it can help capitalize on spillovers and indirect impacts of domestic efforts for shared progress. Rather than disjointed, single-point interventions, an internationally coordinated portfolio of investments creates space for learning, enabling exploration of various decarbonization pathways at once and allowing countries to fail faster, share lessons learned, and avoid repeating the same mistakes. For example, the UNDP is piloting "portfolio sensemaking" exercises to accelerate the process of learning and spillovers across country activities to enhance their impact.[43] Through portfolio-based cooperation, countries can identify where different early stage technologies are best suited to develop efficiently, which can help mitigate first-actor risk if countries pursue innovations aligned with their distinct self-interests, while the spillover benefits of all efforts can be shared jointly across markets. A portfolio approach can also support technological diversity by ensuring countries are collectively supporting the suite of globally necessary solutions.

The IEA recognizes "international collaboration [on technology innovation] can increase effectiveness, bring efficiency benefits and maximise the impact of energy technology innovation efforts," with participants enjoying, for example, access to facilities and expertise, information sharing, accounting for complex feedback loops, and large joint studies. Importantly, cooperation can improve competitiveness "by spreading the costs and risks of RD&D and forming joint ventures," for instance, by capitalizing on the heterogeneity of interests, risk appetites, and domestic market characteristics of different governments working toward a shared goal. Good coordination can identify areas for active cooperation (e.g., research partnerships) and avoid duplication of efforts. Further, international coordination may reduce technology costs by creating larger markets for demonstration. Through coordination, countries may also be able to access international markets they would not have been able to reach individually, for example, if countries with low innovation capacities partner with higher-capacity countries (including South-South partnerships).[44]

Get International Political Commitments and Incentives Right

For many policymakers, the UNFCCC remains the ultimate political signal of norms for international climate action. While the proposals in this report go far beyond UNFCCC finance negotiations by recommending how sovereign governments approach their budgets (and by suggesting roles for developed and developing countries that differ from those in the UNFCCC), optimizing expenditures for decarbonization is very much in line with the objective of the UNFCCC and the Paris Agreement.

There is growing recognition that developed-to-developing country flows are only one—albeit important—piece of the broader set of finance approaches needed for decarbonization (and adaptation). One could envision a UNFCCC decision that recognizes the various roles of public and private finance in meeting Article 2.1c of the Paris Agreement—including roles that go beyond traditional climate finance. We have shown here how investment along the entire technology chain, including investment to dismantle market barriers and foster enabling environments, generates tangible benefit for countries around the world. In that sense, first actors who drive cost reductions in high-cost, early stage technologies generate value just as concessional climate finance does. At the international level, a holistic approach to public expenditures would recognize how benefits of domestic investment in RD&D accrue in other countries alongside traditional climate finance support.

A less sanguine observer might say the UNFCCC is unable to spur more than incremental change of insufficient ambition, and concerns about economic competitiveness preclude the necessary international cooperation. Here, smaller groupings of political and economic leaders may be better positioned to demonstrate ambition and set norms. The history of political progress on climate change shows that binding together major players to pledge to a new norm can be effective. In 2014, the Group of 7 (G7) leaders agreed to a deadline to submit their intended nationally determined contributions ahead of the Paris Agreement; this had been a source of disagreement in the UNFCCC, but UNFCCC parties adopted that same timeline for all countries following the G7 decision. A political signal to demonstrate universal commitment to decarbonization might also ease fears that pursuing decarbonization would reduce competitiveness. Instead, the signal would be that cooperation and a holistic approach are the norm and can create expanded opportunities and markets.[45]

6 Next Steps

Next Steps

Collectively, we have a long way to go until public finance aligns with the vision above. Institutional and political barriers impede the efficient allocation of public finance—and cooperation to that end—for any purpose, let alone for an economy-wide challenge like climate change. To date, climate finance models have struggled to sufficiently capture reality, and a "perfect" model will likely not fix faulty decision-making in time. What is needed is an overhaul in outlook across a global community of decision makers. We believe our proposals can serve as starting points for willing coalitions of stakeholders to take concrete next steps. If nothing else, policymakers realizing they could do their jobs better with a holistic approach would be a valuable first step.

We propose stakeholder-driven workshops as a starting point for building out a holistic approach that will be implementable, best serve governments, and send the right signals to other actors. Through multi-stakeholder convenings, willing actors can foster communities of practice, build capacity around a shared framework, and emphasize ambition that works for everyone. For instance, through multi-stakeholder working groups, governments can cement a shared understanding with major private innovators, manufacturers, and investors of which government interventions (expenditures and policies) best help the private sector move technologies to adoption. Engaging with the concepts from this report firsthand through simulations or guided discussion would equip stakeholders with new mental models and heuristics to support a reevaluation of their current assumptions and modes of operating. Consequently, they may feel motivated and empowered to reconsider the status quo.

In developing actionable approaches, governments are best placed to articulate what is ambitious and still achievable given their competing priorities. Ideally, these workshops would be bottom-up design processes so governments can ensure they are building an approach that reflects real country priorities and desired end uses. Nonetheless, there is also a role for other actors. Cooperative initiatives, international organizations, NGOs and think tanks, academia, and the private sector can play a coordinating role or bring positive external pressure and technical expertise (e.g., evolving insight on technology cost curves) to working groups. Some topics a workshop might explore to build out a holistic approach include:

- *Heuristics and mental models:* What heuristics (other than the technology chain) can help stakeholders visualize how to best organize the undertaking of a holistic approach?

- *Country priorities:* Other than decarbonization, what priorities (e.g., economic growth and job creation) need to be factored in when considering how to finance decarbonization? What is the relationship with stimulus and recovery efforts?

- *Domestic integration:* What are practical and political challenges to a more integrated expenditure process?

- *Sectors:* How must a holistic approach account for the circumstances of different sectors (e.g., land use)?

- *Leveraging the private sector:* What lessons already exist for how governments can best leverage the private sector? Do we need to know more about best practices for driving solutions to adoption?

- *Roles and collaboration:* What are the roles of developed, emerging, and developing economies in a holistic approach? Of non-government stakeholders?

Convenings can also be a useful venue for stakeholders to refine the black box concept. Again, we do not think the goal is for the black box itself to produce expenditure decisions. But if policymakers engage with the black box, they may make it more informative for decision-making and feel more ownership of the concept. The value in building out a more refined and robust representation of the black box should be carefully weighed against its limitations—especially to avoid succumbing to shortcomings of the current orthodoxy described in Section 3.

Allocation of public finance should be based on evolving circumstances rather than deterministic, best-guess forecasts that inevitably offer a narrow reflection of reality. This type of complex systems modeling can be extremely challenging and resource intensive to realize, and it is hard to predict how useful it would be. The goal should not be to encourage replacement of existing models (or those under development) with one only incrementally better. Further, the design of any tools or products should balance complexity with accessibility, ensuring that efforts to build a holistic approach do not ultimately exclude its use by the most important stakeholders. Quite simply, a holistic approach that provides mental models and contributes to behavior changes can deliver real value by influencing the ways policymakers interact, understand their responsibilities, and make recommendations.

To assist stakeholders in exploring the black box, the highly simplified exercise described in Box 5 is available alongside the report.[iv] Some elements that stakeholders might wish to explore through similar exercises are below.

Additional multipliers: The black box in Section 4 includes only a few variables. Integrating other multipliers could enhance future work. For example:

- *Fiscal lever strength:* multiplier to reflect the strength of different public finance measures for driving results (e.g., direct investment versus market signals that usher in private capital), including how the type of actor targeted by the public intervention (e.g., VC or corporates) might drive different amounts of capital and in different markets and stages of technology development.[46]
- *Market size:* availability of capital markets and private investment to overcome valleys of death.
- *Co-benefits:* investments in decarbonization can create tangible value for a country's non-decarbonization priorities, for instance, improved air or water pollution where clean technologies displace fossil fuels; as a result, co-benefits can help drive adoption.

Granularity: Breaking down and more granularly distinguishing between certain variables could help avoid overlap. For example:

- *Competitive advantages* are currently distinguished for "early innovation" and "manufacturing," but a country could hold an advantage at any stage of technology development.
- *Carbon lock-in* could be broken down into multipliers for social, institutional, or regulatory hurdles, the amount of capital stock, and the rate of turnover of capital stock.
- *Enabling environment* also contains elements of complementary infrastructure, as well as a country's political will, regulatory environment, and institutional environment, all of which could be treated independently.
- *Network effects* here are related mostly to complementary infrastructure, but they could also relate to the degree of adoption or degree of technical compatibility, and the resulting low-carbon lock-in, as one or more variables.

Complexity: Keeping in mind possible pitfalls of excessive complexity (especially depending on the application), future work could integrate the following:

- Systems modeling to update multiplier values as a function of technology progress.

[iv] The simulation described is available for download with this report at **https://rmi.org/insight/recasting-the-golden-key**.

- Estimates to account for benefit distribution of investments, including how value accrues domestically and globally, and/or where and when.

Country priorities: Our examination unrealistically applies a country-neutral lens to deconstructing investments in decarbonization. In reality, both the identification and quantification of variables would be more accurate if determined by countries' priorities and circumstances, including:

- *Risk tolerance:* to weed out investments that do not meet certain financial thresholds.

- *Priority markets:* the technologies and sectors a country might be interested in spearheading development within.

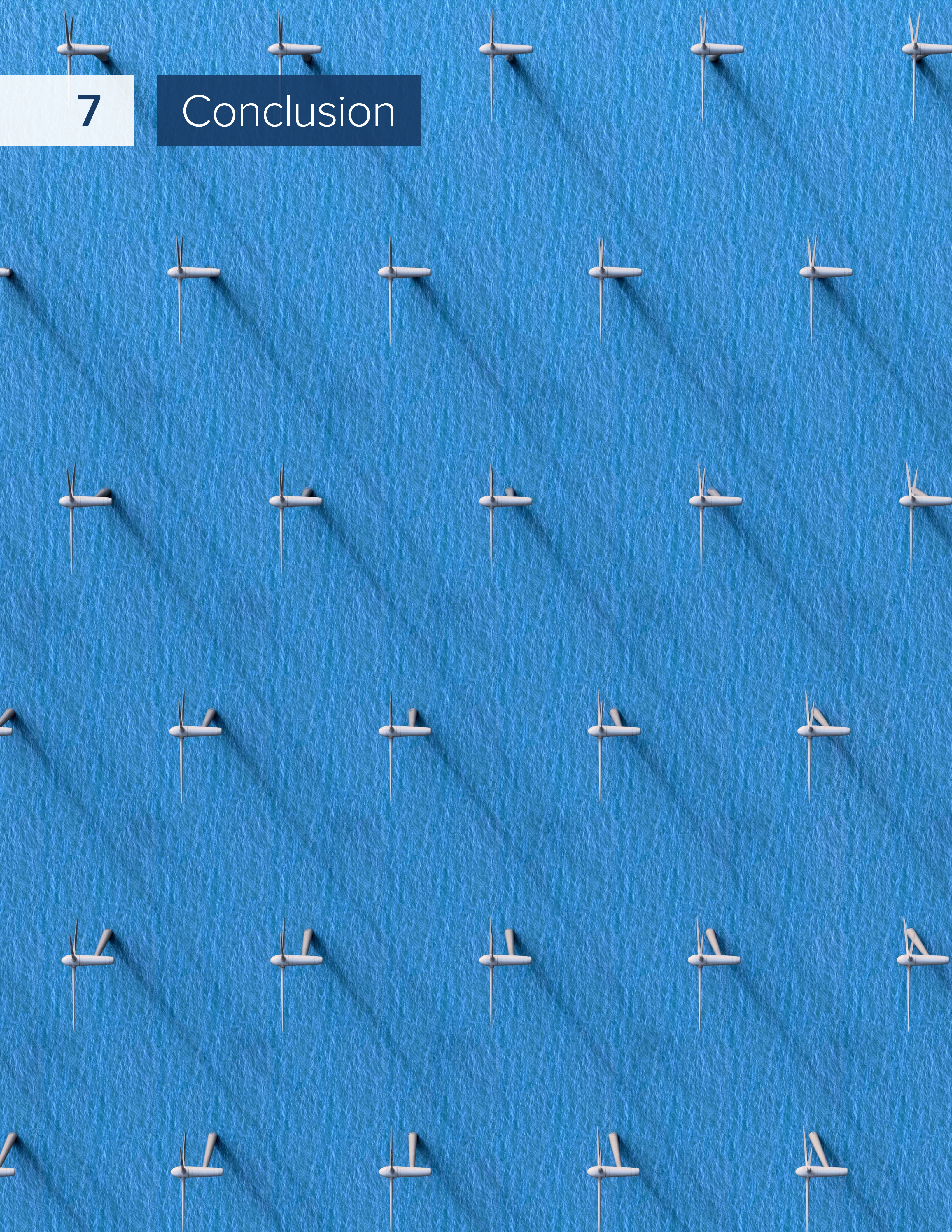
- *Business opportunity:* size of deployment market associated with a given investment.

- *International trust:* openness to coordination with other countries, including willingness to share technological advances or exposure to foreign market dependence.

- *Job creation:* including which technologies or stages of technology development contribute most strongly to domestic job creation, or the type of job creation that will best complement country context.

We see the highest likelihood of the full development and eventual piloting of an integrated approach if an ambitious international initiative fosters the process. This group should have the convening power and networks to bring together the right stakeholders. A venue in which members are used to working toward a shared goal can provide the structure and partnership countries need to embark on this journey together.

7 Conclusion



Conclusion

At the start of the most critical decade for decisive climate action, the world faces both the prospect of a global economic crisis and the opportunity for a clean, equitable future as we build back better. We can only attain that future, though, if we apply our resources better—if we recast the golden key. Given the complexity in predicting how an investment will affect decarbonization, we may never know what the "best" way is to finance decarbonization. But governments can indeed take steps, individually and together, to take a more holistic approach on the road to optimizing their public expenditures for decarbonization. We call on each nation individually, and on the international community collectively, to take up this challenge.
We described a few next steps, but there are many options. Countries will have to find their place in a shared solution. The alternative is a future that does not work for anyone.

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Acknowledgments

The authors thank the following individuals for their input on this work. This acknowledgment does not imply endorsement by these individuals or institutions of the views presented in this report.

Josh Agenbroad	Rocky Mountain Institute
Blandine Barreau	International Energy Agency
Simon Bennett	International Energy Agency
Dan Besley	World Bank
Gabriela Blatter	Switzerland, Federal Office for the Environment
Charlie Bloch	Rocky Mountain Institute
Jessica Brown	ClimateWorks Foundation
Barbara Buchner	Climate Policy Initiative
Gionata Castaldi	Italy, Ministry of Economy and Finance
Isabel Cavelier	
June Choi	Climate Policy Initiative
Jonathan Coony	World Bank
Janine Coye-Felson	Permanent Mission of Belize to the United Nations
Jennie Dodson	Mission Innovation
Aldo Ravazzi Douvan	Italy, Ministry of Environment
Lorena Gonzalez	Office of the UN Secretary General
Stephane Hallegatte	World Bank
Steve Hammer	World Bank
Dominic Hofstetter	Climate-KIC
Raphaël Jachnik	OECD
Krutarth Jhaveri	Rocky Mountain Institute
Farrukh Khan	
Jean-Baptiste Le Marois	International Energy Agency
David Levaï	Institute for Sustainable Development and International Relations (IDDRI), UN Foundation

Shuang Liu	World Resources Institute
Tyeler Matsuo	Rocky Mountain Institute
Christophe McGlade	International Energy Agency
James Mitchell	Rocky Mountain Institute
Rob Moore	United Kingdom Cabinet Office
Benito Mueller	University of Oxford
Katie Mulvaney	Rocky Mountain Institute
Greg Nemet	University of Wisconsin-Madison
Scherie Nicol	OECD
Pete Ogden	United Nations Foundation
Padraig Oliver	UN Framework Convention on Climate Change
Araceli Fernandez Pales	International Energy Agency
Celine Ramstein	World Bank
Dan Schory	
Cecilia Tam	OECD
Iain Thom	Scottish Parliament Information Center
Griffin Thompson	
Joe Thwaites	World Resources Institute
Bella Tonkonogy	Climate Policy Initiative
David Turk	International Energy Agency
Michael Waldron	International Energy Agency
Hara Wang	Rocky Mountain Institute
Daniel Wetzel	International Energy Agency
Cyril Yee	Rocky Mountain Institute
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