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Climate Action to Unlock the Inclusive Growth Story of the 21st Century

by Amar Bhattacharya, Maksym Ivanyna, William Oman, and Nicholas Stern

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Climate Action to Unlock the Inclusive Growth Story of the 21st Century

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Abstract

Climate change is a major threat to the sustainability and inclusiveness of our societies, and to the planet's habitability. A just transition to a low-carbon economy is the only viable way forward. This paper reviews the climate change challenge. It stresses the criticality of systems changes (energy, transport, urban, land use, water) in a climate-challenged world, and the importance of infrastructure investment geared toward such systems changes. The key policies to enable the transition are: public spending on and investment frameworks for sustainable infrastructure, pricing carbon, regulations, promoting sustainable use of natural resources, scaling up and aligning finance with climate objectives, low-carbon industrial and innovation policies, building resilience and adaptation, better measurement of well-being and sustainability, and providing information and education on climate risks. Implemented well, climate action would unlock the inclusive growth story of the 21st century, making our societies more sustainable, inclusive, and prosperous.

JEL Classification Numbers: Q01, Q54, H23, H4, O13

Keywords: climate change, sustainable development, just transition, low-carbon economy, inclusive growth

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I. INTRODUCTION

Prosperity and well-being can be sustained and increased over time only if humanity safeguards the ecological basis of modern societies – critical global commons like fresh air, clean water, sustainable food supplies, biodiversity, and a stable climate. If natural wealth is not preserved, living standards will inevitably deteriorate, and ultimately the planet's habitability will be threatened. Prosperity will not be shared with future generations, and the poor will suffer disproportionately from the negative consequences. Inclusive growth requires sustainability. [2]

The bad news is that the economic growth models of the 20th century are not sustainable. These models – albeit diverse – have undeniably produced material progress: income per capita has increased multiple times, billions have been lifted out of poverty, and the average life span has increased by decades. At the same time, these growth models have had an unprecedented ecological footprint that threatens the viability of modern societies. Indeed, economic activity has for the past two centuries – and particularly the past seventy years – driven environmental change on a global, even geological scale (Crutzen 2002).[3] It has altered the chemical composition of the ocean and atmosphere, led to freshwater overuse and reduction of wildlife populations at an alarming rate, and brought the Earth close to an irreversible disruption in key planetary systems – those that are necessary for human development as we know it (Rockström, et al. 2009).

One of the key disrupted systems is the changing climate. Every year, the world's economy releases several dozen gigatons of greenhouse gases (GHGs) into the atmosphere. As a result, the average global temperature has already risen by more than 1°C since the 19th century. Nine of the ten warmest years on record have occurred since 2005 (NOAA 2020). Global warming causes sea-level rise, increasing frequency and severity of natural disasters, and higher pressure on ecosystems – resulting in severe socio-economic damage across the globe. If GHG emissions continue unabated at the current pace, humanity has only about a decade before it risks triggering catastrophic climate scenarios that would threaten the livability of the planet for itself and other species (Stern 2015, M. Weitzman 2011, Westerhold, et al. 2020).

Carbon-intensive growth – that is, growth fueled by greenhouse gas emissions – is strikingly non-inclusive. The costs and risks of climate change have been systematically underestimated (DeFries et al. 2019). Climate change disproportionately affects the poor, as they suffer higher impacts from the shocks and long-term impacts of climate change and have fewer means to adapt. If unchecked, climate change can lead to hundreds of millions of displaced people mostly in the developing world. Carbon-intensive growth also puts at risk jobs that will become stranded in the future, when polluting sectors will have to be rapidly retired to avoid catastrophic climate change. The more decarbonization is delayed, the more disorderly future

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[2] For the purpose of this paper, economic growth refers to increases in the production of goods and services that are valued by people, providing the means for a better standard of living. Inclusion refers to broadly sharing these improvements of living standards among all groups in society, including the opportunity to access basic services, participation in economic life, and empowerment in social and political life. Sustainability means that the current living standards can be sustained into the future of both current and future generations.

[3] This acceleration in Earth system indicators since 1950 has come to be known as the Great Acceleration (Steffen, et al. 2015).

shocks to polluting sectors will be. Large numbers of jobs will become stranded, incomes will be lost, and wealth will be destroyed, driving many millions into poverty. Crucially, those who are set to suffer most from climate change have contributed – and continue to contribute – least to it. The consumption-based annual emissions of the wealthiest 1 percent of the global population account for more than twice the combined emissions of the poorest 50 percent (UNEP 2020).

In contrast, decisive climate action has become increasingly attractive. Thanks to rapid technological advances, low-carbon solutions are now less costly than fossil fuel-based investments across a broad segment of economic activity. Social norms are changing too, as hundreds of countries, regions, cities, and businesses are pledging carbon-neutrality by mid-century and there is growing public support for climate action.[4]

Crucially, the benefit of effective climate action is potentially immense. The evidence mounts that climate action is not a cost in terms of growth, development and jobs but rather an attractive path to more inclusive, resilient and sustainable growth (Stern 2021). It can help the world economy recover from the effects of the COVID-19 pandemic by providing an immediate impetus to economic demand, creating millions of jobs, training, and investment opportunities. Over the medium term, it can spur innovation and discovery and create new sources of economic growth. It would also lift many millions out of poverty and reduce inequalities, while delivering multiple environmental co-benefits, notably clean air and water, and preserved natural wealth (Stern 2015, Meckling and Allan 2020). Over the longer term it is the only path to a sustainable future by stabilizing climate and making our economies more resilient. Indeed as the New Climate Economy has underscored, it can "unlock the inclusive growth story of the 21st century" (The Global Commission on the Economy and Climate 2018).

A sustainable, more inclusive, and more resilient growth model requires accelerating transformation in key economic systems – a shift to clean energy systems, smart urban development, sustainable land use, wise water management, and a circular industrial economy. Design and management of cities in particular will be central given their growing importance for climate impact and resilience. Investment in sustainable and resilient infrastructure is central to accelerating the transformation (The Global Commission on the Economy and Climate 2018, IMF 2020). The next 10-15 years are critical. Locking the infrastructure investment in high-carbon assets would delay decarbonization by decades and make it progressively more expensive. At the same time, investing in low-carbon infrastructure is getting increasingly affordable, and it comes with multiple co-benefits such as cleaner air, better health, less congestion and preserved and fruitful ecosystems.

To enable the transformation, governments, working in partnersip with other stakeholders, should have a shared national vision and strategy for sustainable and inclusive growth that integrates climate, including through long-term planning, well-articulated nationally determined contributions to global mitigation efforts, and sector investment programs (Stern and Stiglitz 2021). Design of the key economic systems must be an integral part of the strategy. The strategy should be comprised of a broad package of tools and policies to:

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[4] Carbon-neutrality means balancing emissions of carbon dioxide with its removal.

- Eliminate fossil fuel subsidies, and put a price on carbon, while mitigating the impact on the poor and affected workers, businesses, and regions;
- Reinforce carbon pricing with sector-specific policies: regulations, energy efficiency standards, feebates;
- Promote sustainable use of natural resources, using such policy measures as payments for ecosystem services, regulations, agricultural and water subsidies reform, incentives for a circular economy to decouple economic growth and material use;
- Boost public investment in sustainable and resilient infrastructure, including in nature-based solutions – restoration of degraded lands and conservation of existing ecosystems while mitigating the impact on the poor;
- Align finance with climate objectives: manage financial stability risks posed by climate change, align social and private returns to green investment, mobilize resources for investment, including a major boost to international climate finance, and make monetary and supervisory policies consistent with net-zero emission objectives;
- Deploy industrial and other policies to drive climate-friendly innovation, including in digitization, new materials, life sciences and production processes, with a focus on the coordination of policy areas and on long-term policies and policy planning;
- Provide information and public discussion on social norms and behaviors to lower energy demand and carbon intensity of consumption and business activity, and educate the public about climate change risks, including early warning systems and evacuation plans in case of natural disasters;
- Develop insurance instruments and social safety nets to mitigate the immediate impact of climate shocks;
- Promote active labor market policies, entrepreneurship, financial inclusion, regional investment strategies to facilitate structural transformation and the transition to a low-carbon economy for affected workers, businesses, and regions.
- More fundamentally: integrate sustainability considerations into public financial management and corporate governance; use better models and go beyond GDP when deciding on policy priorities and measuring well-being and sustainability.

The climate challenge is exacerbated by the COVID-19 pandemic, which has claimed millions of lives, caused severe economic damage, and amplified inequalities. The pandemic has highlighted that the old normal was deeply fragile and dangerous. The damages due to climate change and biodiversity loss could be even bigger and more lasting than those we are experiencing from COVID-19. Building back better – creating sustainable, resilient, and inclusive economies – is a priority as countries are crafting recovery policy packages (The Coalition of Finance Ministers for Climate Actions 2020, IMF 2020). A sustainable recovery can improve productivity, new forms of employment and support the transition to a zero-carbon and climate-resilient economy. It can boost employment in areas that need it most; helping to avoid extended and severe unemployment, which can de-stabilize politics and society. And it can generate strong multipliers for economic recovery and growth and can be accompanied by powerful co-benefits including reduced congestion and pollution.

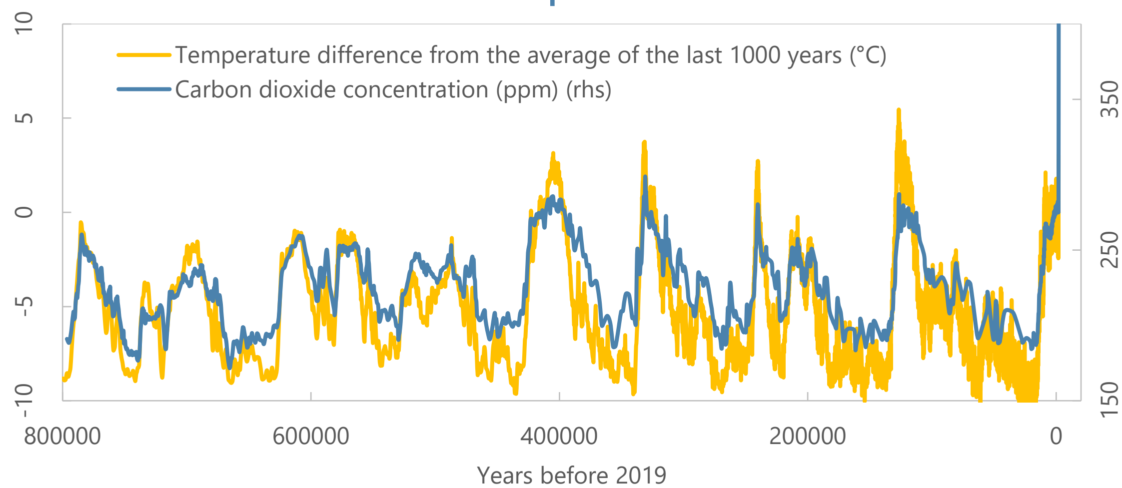
This paper provides an overview of the climate challenge that we face, and of the transformation that is required, with a focus on the critical importance of making our economies both sustainable and inclusive.

II. Science and Economics of Climate Change

A. What Is Climate Change?

Climate change results from a combination of two major factors. The first is the greenhouse effect. Discovered and thoroughly described already in 19th century (Fourier 1824,

Figure 1. Carbon Dioxide Concentration Goes Hand in Hand with Temperature



Source: NOAA, Lüthi, et al. 2008, and Jouzel, et al. 2007, WMO 2019 (the CO_2 concentration for 2019)
Note: The data comes from the composition of air trapped in ice cores in Antarctica

Tyndall 1861, Arrhenius 1896), it is about the property of certain gases (so called greenhouse gases – GHGs) to trap solar heat in the atmosphere and reflect part of it back to the Earth's surface. The key GHGs in the atmosphere are water vapor, methane, nitrous oxide, and most importantly carbon dioxide – the product of our breathing and fossil-fuel burning, among other processes. Part of the carbon dioxide is absorbed by plants and phytoplankton, or dissolves into oceans, but the unabsorbed extra, once released, stays in the atmosphere for centuries. In the end, higher concentration of carbon dioxide and other GHGs means more solar heat is trapped, and hence the planet gets warmer – a robust relationship established using close to a million of years of data (Figure 1).

The second factor in climate change is increased GHG emissions due to economic activity. On average, global GDP has increased by almost 3.5 percent annually since 1960, and carbon dioxide emissions followed, albeit at a slightly slower pace – 2.5 percent. Ever increasing emissions combined with a limited absorptive capacity of the planet have resulted in an unprecedented concentration of carbon dioxide in the atmosphere – as much as 410 parts per million (ppm)[5] in 2019 versus 278 ppm before the industrial revolution (in 1750) (WMO 2019) – a level last seen around 3.2 million years ago, when global temperatures were 2°C warmer and sea level was 20 meters higher than present (de la Vega, et al. 2020).[6] The speed at which the atmospheric composition changes is also very worrisome. In the last 800,000 years, carbon dioxide concentration has never changed by more than 25 ppm per thousand years. Global economic activity has led to the addition of 25 ppm every fifteen years since 1960 (Weitzman 2011).

The result of the combination of the greenhouse effect and increased atmospheric concentration of GHGs is that our planet is warming. The average global temperature has already increased by more than 1°C since the end of 19th century (NOAA 2020). If GHG emissions continue their current trend – a so-called Representative Concentration Pathway 8.5 (RCP8.5) scenario – the projected temperature increase is 4-6°C by 2100 (IPCC 2014) – an unprecedented change likely unseen in millions of years (Hansen, et al. 2013).[7]

Other climate conditions are changing too. Increased evaporation combined with other factors changes precipitation patterns, generally making dry areas even drier, and wet areas even wetter (IPCC 2014). The weather also gets more volatile: heat waves and cold spells, as well as torrential rains and dry spells, increase in frequency. This volatility then leads to a higher chance of natural extreme events: droughts, floods, tropical cyclones, forest fires.

With changing climate come large-scale changes in the planet's key ecosystems. The sea level is projected to rise by about one meter by 2100 under the RCP8.5 scenario, prompted by expanding warm water and melting polar glaciers (IPCC 2014). Mountain glaciers are also melting at an accelerating pace (Marshall 2014).[8] Oceanic water gets not only warmer but also more acidic – a process of so-called ocean acidification – threatening many marine species. On land too, climate change is one of the key reasons for the rapid loss of biodiversity, as many species do not have time to adapt. Some species do, and even expand their area of habitat, but often with dire consequences: the spread of malaria in the case of mosquitos (Reiter 2001), Lyme disease in the case of ticks (Dumic and Severnini 2018), or the decline of forests due to bark beetle (Katz 2017).

The larger and faster climate change occurs, the more it affects the environment, and the effect is highly non-linear. For example, warming of 2°C instead of 1.5°C would essentially wipe out all coral reefs on this planet (instead of 70-90 percent), and expose 37 percent of the

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[5] "Parts per million" is a way to report small concentrations of gases or other substances. Essentially, carbon dioxide concentration of X ppm means X molecules of carbon dioxide in one million of molecules of air.

[6] The amount of anthropogenic emissions this and (projected) next century is comparable to the total released during the end-Triassic pulses of volcanic activity in the Central Atlantic Magmatic Province – an event that wiped out more than three quarters of species on Earth due to the resulting global warming and ocean acidification (Capriolo, et al. 2020).

[7] Just to put this change into perspective, the Last Glacial Maximum (e.g. the last Ice Age), about 20,000 years ago, was the period when polar glaciers would reach New York and Berlin, most of the non-iced world was either desert, tundra or dry savannah, and the sea level was 125 meters lower than now. Back then the average temperature was just about 5-6°C lower than now (Clark, et al. 2009).

[8] In 2014 Okjökull (Ok) was the first glacier in Iceland officially declared dead.

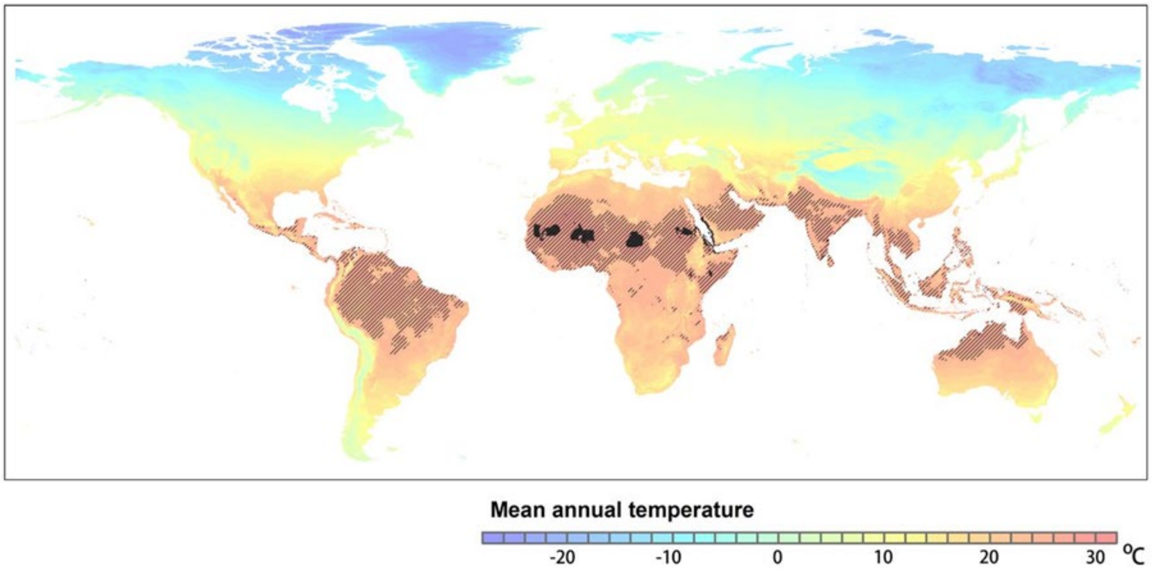
population to extreme heat at least once every five years (instead of 14 percent) (IPCC 2018). Going above 2°C significantly increases the probability of even larger, nearly unpredictable and likely irreversible environmental changes. Examples include methane runoff from Arctic permafrost or hydrate deposits in the Arctic Ocean, which would unleash runaway warming; the melting of Greenland or the West Antarctic ice sheets, which would raise sea levels by several meters; or an abrupt biodiversity loss. Large ecosystems could drastically change through what are known as "tipping points" or a global cascade of tipping points: the Amazon rainforest could suddenly turn into a savannah; the West African and Indian monsoon patterns could swiftly change; major oceanic currents could slow and change directions (Preuss 2008, Lenton, et al. 2019, Trisos, Merow and Pigot 2020, Staal, et al. 2020, DeFries, et al. 2019). Changes like these would not only drastically disrupt our normal way of living, but could make the planet uninhabitable.

B. Socio-Economic Consequences of Climate Change

Even for small temperature increases, climate change brings about substantial socioeconomic damages and exacerbates poverty and inequalities. Key channels of impact are disruptions to agriculture, lower labor productivity, damage due to natural disasters, and sea-level rise. Climate change also creates food security and water security risks in developing countries.

Historical micro-level evidence suggests that agricultural output and labor productivity are significantly adversely affected by climate change. Even though no country is immune, the damages are larger in poorer countries, as these countries' socioeconomic systems are typically less able to cope with climate shocks: people there have less resources to adapt, and tend to reside in hotter areas, where the marginal impact of additional warming is larger (Burke, Hsiang and Miguel 2015, IMF 2017, IPCC 2018). Climate change has already increased global between-country inequality by 25 percent over the past half century (Diffenbaugh and Burke 2019). Without a meaningful mitigation effort, the situation will likely worsen in future: by 2070, some estimates project that, under business-as-usual scenarios, 3.5 billion people – overwhelmingly in developing countries – will reside in areas with mean annual temperature of over 29°C. Such annual averages are currently observed only in a few sparsely inhabited regions of the Sahara Desert (Figure 2). Within countries, climate change also disproportionately affects the poor (Hsiang, Oliva and Walker 2019). By 2030, it could push over 100 million people into extreme poverty, primarily because of disrupted food production, lower labor productivity due to deteriorating health, and natural disasters (World Bank 2020).

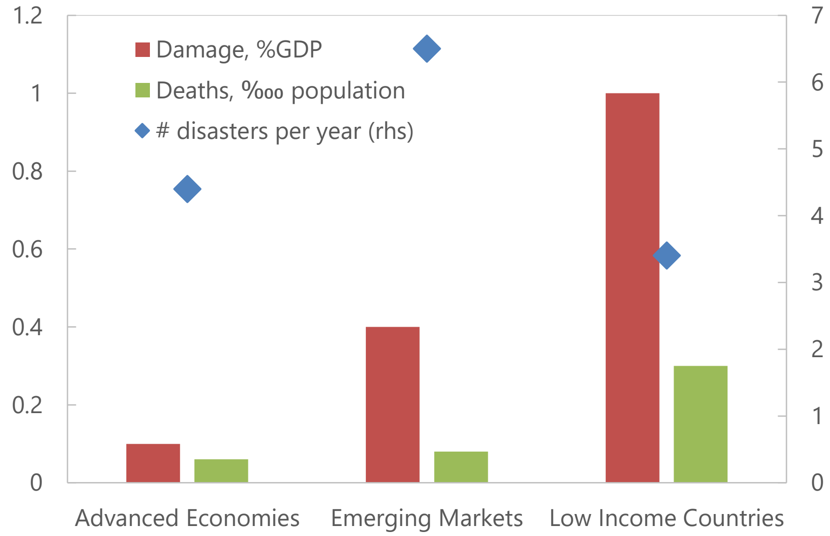
Figure 2. Significant Expansion of Areas Hotter than 29°C on Average by 2070



Source: Reprinted from (Xu, et al. 2020).
Note: Small dark areas are those with mean average temperature (MAT) of over 29°C at present climate. Shaded areas are those with expected MAT of over 29°C by 2070 under RCP8.5 scenario. Background colors represent current MATs

Natural disasters claim thousands of lives and billions of US dollars of losses every year. No country is spared a disaster risk, but low income countries are suffering more damages relative to their economy, and more deaths relative to their population (Figure 3). Poorer people are not necessarily more exposed to natural disasters, but they are more vulnerable, as they live in lower-quality housing, rely more on fragile infrastructure (for example, unpaved roads) and on vulnerable sources of income, such as income from agriculture or ecosystems (World Bank 2020). In addition, weaker organizational capacities and a lower supply of skilled workers – which are typical of poorer countries – are expected to exacerbate damages by making reconstruction following extremes more difficult, which increases total damages from natural disasters (Hallegatte et al. 2007).

Figure 3. Frequency and Magnitude of Natural Disasters in 1980-2020



Source: EM-DAT, average 1980-2020. IMF country classification.

Sea level rise is projected to displace 630 million people by 2100 under the RCP8.5 (high emissions) scenario (Kulp and Strauss 2019). The majority of the displaced are in developing South-East Asia, which exacerbates global inequalities further.

The damage from climate change is not limited to the channels above, and there is considerable geographic variation in how it manifests itself. For example, in the U.S., it is projected that extreme heat will impose large health, energy, and labor costs on Southern states; sea-level rise and hurricanes are projected to impact coasts; humidity levels will require infrastructure restructuring in the North-East; lower crop productivity will impact land markets across the country; and more frequent wildfires and water shortages will impact Western states (Houser, et al. 2015).

More generally, climate change is likely to uncover previously hidden interdependencies between the economy and natural systems, revealing new and potentially enormous disruptions and social costs (DeFries, et al. 2019). Indeed, large output losses and sharp increases in poverty and inequality several decades in the future are likely to occur through channels other than short-term temperature variations.[9] Such channels include the collapse of ecosystems, mass migrations, conflicts, and so forth. It is essential, therefore, to limit the extent of climate change in order to minimize the risk of unpredictable catastrophic outcomes.

[9] See Appendix I for a detailed discussion of socioeconomic damages due to climate change and methods to assess them.

C. Other Environmental Threats

Climate change is not the only phenomenon that threatens the sustainability of modern societies. Many other critical components of ecological conditions are under threat:

- ***Release of chemically active nitrogen and phosphorus into lakes and oceans*** – mostly due to excessive use of chemical fertilizers in agriculture – results in low content of oxygen in the water (so-called anoxic waters) and conditions where only certain bacteria and fungi can survive. Large areas of anoxic waters are already present around the globe, e.g. in the Baltic Sea (Conley and et al. 2009), and if nitrogen and phosphorus release is left unchecked the whole ocean may be under threat.

- ***Biodiversity loss*** is orders of magnitude higher than what is normally observed in the fossil record (Rockström, et al. 2009). The biosphere, on which humanity depends, is being eroded to an unprecedented degree, while biodiversity is declining faster than at any time in human history (IPBES 2020). This is in part due to climate change, but also due to habitat loss, invasive species, and unsustainable harvesting. The Dasgupta Review on "The Economics of Biodiversity" clearly demonstrates that biodiversity is crucial to economic growth, adaptation, and resilience, and it is a major source for innovation (Dasgupta 2021). Yet, not only do hundreds of species go extinct every year, but the abundance of surviving wildlife has critically decreased since 1970 – for example, by as much as 83 percent for freshwater reptiles (WWF 2018). Over ninety percent of fisheries nowadays are either fully exploited or overexploited (FAO 2018).

- ***Chemical pollution*** is another area that challenges the global ecosystem. Globally, 100 million metric tons of plastic waste are dumped into nature every year – the pollution getting worse during the COVID-19 crisis. Traces of plastic are found even at the bottom of the Mariana Trench or in the Arctic sea ice, and the average person ingests five grams of microplastic every week (WWF 2019, Reuters 2020).

- ***Local air pollution***, in particular due to fossil-fuel burning, reduces the average person's lifespan by three years, and is responsible for an estimated 6.5 million deaths annually (Lelieveld, et al. 2020).

- ***Unsustainable freshwater use***, combined with ever less predictable rainfall patterns, causes more frequent water shortages and droughts, leading to harvest loss, malnutrition, and eventually social conflict.

- ***Soil erosion*** due to unsustainable farming practices threatens food production.

- ***Deforestation*** goes on in many regions around the globe, especially in the tropics – threatening not only global biodiversity and climate, but also local eco-services like clean air and water (IUCN 2017). From 2001 to 2019 386Mha of tree cover was lost globally— an area equivalent to six times France (Global Forest Watch 2020).

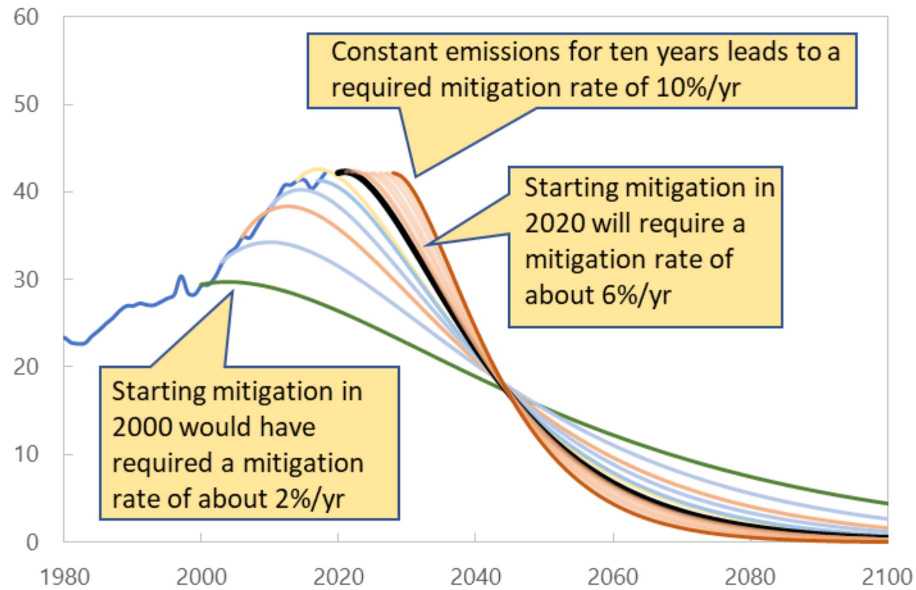
The environmental issues above are tightly linked to each other and to climate change, and they are often driven by the same factors or misguided policies. For example, fossil-fuel burning is a major cause of climate change and local air pollution. Unsustainable farming practices erode soil, deplete freshwater reservoirs, reduce forest area, and disrupt marine ecosystems due to nutrients run-off, which in turn reduces the planet's ability to absorb carbon dioxide and leads to loss of biodiversity – itself essential to our ability to adapt to climate change. Wildlife habitat loss, due to land use changes and unsustainable harvesting, not only fuels climate change but also increases the propensity of wildlife to transmit viruses – among animal species, and often to human beings, as in case of Lyme disease, Ebola, HIV/AIDS or COVID-19 (Vidal 2020, Allan, Keesing and Ostfeld 2003, IPBES 2020).[10] As with climate change, a degraded environment disproportionately hurts the poor, since they tend to live in more affected areas and have less resources to adapt. Tackling climate change can therefore generate many environmental and inclusion co-benefits, and can become self-reinforcing.

D. What Needs to Be Done?

Returning to a sustainable development path requires stabilizing our planet's climate, and doing so at a level at which large-scale catastrophic outcomes have a very low chance of materializing. That is, under the current scientific consensus, the global temperature increase must be limited to no more than 2°C above pre-industrial levels, though even this upper boundary may turn out to be unsafe as scientists are still learning about the planet's response to a temperature shock of this size (Lenton, et al. 2019). Environmental degradation must also be reversed, and adaptation measures must be put in place to tackle the climate changes that are bound to occur despite mitigation efforts. Importantly, the transition must be just and inclusive, and account for development needs and elimination of poverty across the world.

[10] More than half a million unknown viruses in nature could still infect people if contacts with wildlife and habitat loss are not dramatically reduced. Climate change aggravates the issue not least because it induces migration of both people and wildlife, and because of appearance of new viruses from melting glaciers (IPBES 2020, Zhong, et al. 2020).

Figure 4. CO2 Emissions Must Go Down to Limit the Global Warming



Source: Reprinted from (Andrew 2020), data from Global Carbon Project.
Note: The mitigation curves are estimated so that there is a 66 percent chance of staying below 2°C (IPCC 2018). The mitigation curves for staying below 1.5°C are steeper. The calculations are subject to significant uncertainties, including the emission paths of GHGs other than CO2.

Limiting global warming to 2°C means a 25-30 percent reduction in CO_2 emissions by 2030, and eventually reaching net-zero by 2080 (**Figure 4**),[11] and a similar mitigation path for other GHGs (Climate Action Tracker 2020). A safer goal of 1.5°C warming requires carbon-neutrality by 2050-2060 (Climate Action Tracker 2020). The 2018 IPCC Special Report on Global Warming of 1.5°C played a key role in the shift in understanding and public opinion by highlighting the already evident impacts of climate change and the grave risks of global warming beyond 1.5°C (IPCC 2018). Waiting can hardly be justified. The transition to a low-carbon economy (e.g. net zero emissions) will have to happen anyway – non-zero GHG emissions in the long run means perpetual warming, which will eventually make our planet uninhabitable. Waiting will only make the transition less gradual—as the global carbon budget is being depleted—and increase the likelihood of irreversible catastrophic outcomes (Stern 2015). Rapid decarbonization – when entire carbon-intensive industries need to be abruptly retired in the face of runaway climate change – would also create stranded assets, regions, and jobs. The stranded jobs would have a large impact on poor countries, as many workers there would lose their incomes and pension rights – their only ticket out of poverty (Bhattacharya and Stern 2020).

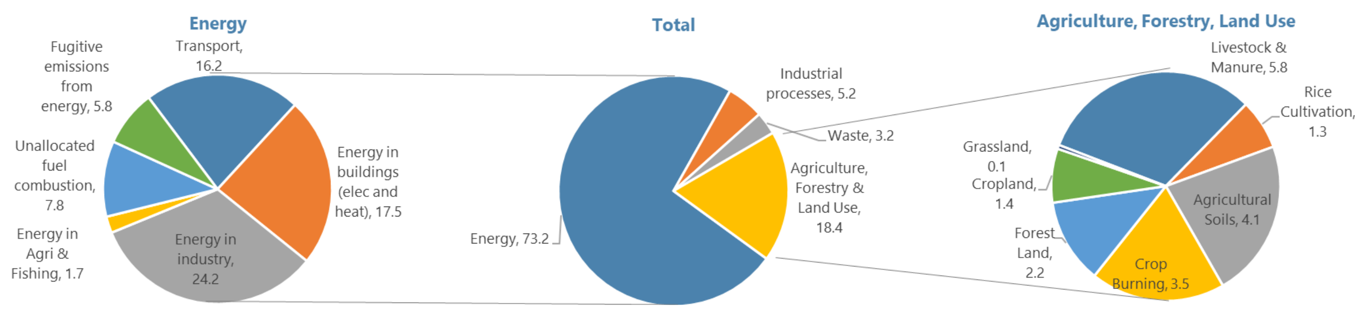
Encouragingly, most major economies have committed to a target of net-zero emissions by mid-century and all G7 countries have set more ambitious targets for reduction in emissions

[11] Net-zero means GHG emissions net of those removed from the atmosphere, for example by restored forests or potentially by direct carbon capture and storage technologies, though these technologies are still at the early stages of their development.

by 2030 as a first step towards that goal.[12] Although these commitments mark an important shift, all countries will need to come on board, and more ambitious cuts will be needed by 2030 from present emission levels to put the world on track to meet the 1.5°C target. It is important to take strong and early steps and avoid backloading. Credible early steps, especially if taken in a coordinated manner, can help set expectations and unleash the investment and innovation needed for accelerated change.

The transition requires comprehensive structural changes in all emitting sectors. Currently, energy sector accounts for almost three quarters of the emissions due to fossil-fuel burning for electricity, heat, and transportation, as well as fugitive methane emissions from oil and natural gas extraction (Figure 5). Over five percent of GHG are released because of industrial processes - production of steel and cement, but also plastic and others. Agriculture, forestry and land use are responsible for over 18 percent of the emissions, mainly due to deforestation, crop burning, livestock operations, and the use of chemical fertilizer. Three percent of the emissions, mostly methane, come from landfills and wastewater treatment. The carbon-intensive industrial processes and infrastructure must be transformed by innovation and investment, complemented by sustainable consumption choices by households.

Figure 5. GHG Emissions Across the Economy



Source: Adapted from Our World in Data, data from Climate Watch, World Resources Institute, as of 2016.

Note: GHG emissions from different gases are expressed in CO_2 equivalents, reflecting the global warming potential of these gases compared to CO_2.

This transition is not going to be easy. Climate change is a negative externality: without appropriate policies, polluters do not bear the full cost they inflict on current and future societies. This externality is uniquely challenging: it is global in scope and impacts; it involves significant uncertainty and risk in the scientific chain of causation; it is long-term; and its effects are

[12] In June 2019, the United Kingdom became the first major economy to commit to the net-zero target by 2050. This was followed by the European Union in December 2019. In October 2020, Japan and Korea committed to a net-zero target by 2050, as did China to net-zero by 2060 in December 2020 and the US to net-zero by 2050 with the incoming Biden administration. All of the G7 countries have followed this commitment by setting targets of emission reduction close to or in excess of 50 percent by 2030 compared to 2005 levels that were announced at the Major Economies Forum on Climate and Energy April 22-23, 2021.

potentially enormous and irreversible.[13] As a consequence, governments have a decisive role to play in mitigation, and they need to cooperate internationally.

As hard as it is to cooperate, countries have found ways to do so and to make progress in dealing with climate change. The Paris Agreement of 2015 was signed by 197 parties (members of United Nations). Its aim is to "strengthen the global response to the threat of climate change by keeping a global temperature rise this century well below 2 degrees Celsius above pre-industrial levels and to pursue efforts to limit the temperature increase even further to 1.5 degrees Celsius" (UNFCCC 2020). Each country is supposed to submit its own plan of mitigation and adaptation efforts – so-called nationally determined contribution (NDCs), and a special UN agency (UNFCCC secretariat) is responsible for tracking the progress. A major problem at present is that the NDCs that have been submitted, even if implemented, are consistent with about 3°C warming (UNEP 2019). Countries need to step up their efforts to return to sustainability. All G7 countries have recently pledged to become carbon-neutral by mid-century. They were among hundreds of other countries, regions, and businesses.[14] These pledges are examples to follow, but they must be accompanied by coherent decarbonization strategies.

The good news is that, if properly designed, climate action can be a powerful source of sustainable, resilient, and inclusive growth. The benefits of low-carbon development have become increasingly evident in terms of the potential boost to growth and productivity, better cities and communities where we can be more productive and healthier, and ecosystems that are more fruitful and resilient; and it is the only path to a sustainable future for people and planet. We explore the policy options in the next section.

III. CLIMATE ACTION OVERVIEW: ACCELERATING TRANSFORMATION IN KEY ECONOMIC SYSTEMS

A sustainable, more inclusive, and more resilient growth model involves accelerating transformation in five key economic systems (The Global Commission on the Economy and Climate 2018):

- ***Clean energy systems.*** To be in line with the climate objectives, the composition of energy supply must change from a primary energy mix that is over 80 percent based on fossil fuels, as is the case now, to relying predominantly on renewables by 2050, complemented by expanded storage capacity and smart transmission grids (Bhattacharya, Meltzer, et al. 2016). Shifting investment patterns from fossil fuels to renewables is key, and the world is now adding more renewable power capacity than from all fossil fuels combined. Still, as of 2020 about forty percent of total global energy investment was concentrated in the fossil fuel sector (IEA 2021). Decarbonization of power systems combined with decentralized electrification technologies can provide easier access to energy services for those who currently lack it, build resilience to natural disasters, strengthen energy security, and reduce air pollution.

[13] More details in Appendix II.

[14] The details of the pledges differ. The updated list of "Climate Ambition Alliance: Net Zero 2050" can be found at https://climateaction.unfccc.int/views/cooperative-initiative-details.html?id=94.

- ***Smarter urban development.*** By 2050 two thirds of the world's population is expected to live in cities, using the infrastructure that is largely planned and built today (The Global Commission on the Economy and Climate 2018). Making this infrastructure sustainable and resilient is crucial both to the economic growth and to the quality of living for billions of people, including the poor. The space for progress is apparent, as many cities are plagued by chronic congestion and air pollution, and over a billion urban residents live in informal settlements (UN Habitat 2016). Investment priorities include expansion of public and non-motorised transport networks; housing and commercial buildings retrofits; slum upgrading; and expansion of green areas. Important are also policies to make cities denser and to prevent urban sprawl. These policies would reduce the infrastructure cost per capita, and leave more land for conservation or agriculture, as urban developments around the world already take up an area larger than India (SEDAC 2020). Denser cities also emit less GHGs per capita (The Global Commission on the Economy and Climate 2018).

- ***Sustainable land use.*** The shift to more sustainable forms of agriculture combined with stronger protection and restoration of ecosystems can be a powerful climate solution, while creating millions of jobs, improving food security, and providing livelihoods (e.g. in form of payments for ecosystem services), especially for smallholder farmers in developing countries. In addition, restoration of natural capital, especially forests and coastal ecosystems, can make our societies resilient to extreme weather events, as well as slow onset changes like desertification or sea level rise.

  The nature-based solutions is often-overlooked area with large social return.[15] For example, restoring just twelve percent of degraded agricultural land can feed additional 200 million people by 2030 – reducing malnutrition by 25 percent globally (The Global Commission on the Economy and Climate 2018). Planting trees – even if done solely in unforested areas, which are currently unused by economic activity and that can naturally support forests – can store up to 25 percent of the current atmospheric carbon pool – over 75 percent of what modern societies have added since the Industrial Revolution (Bastin, et al. 2019). Expanding existing protected areas by a factor of two[16] would provide adequate habitat and a space to adapt to mild climate changes for most animal species on the planet, thus putting a halt on the biodiversity loss (Hanson, et al. 2020). At the same time, investment in sustainable agriculture has a dramatic potential to increase cropland efficiency – by two times if crops were grown where they are most productive, and attainable crop yields were achieved globally (Folberth, et al. 2020).

- ***Wise water management.*** Today, 2.1 billion live without safe, readily available water supply at home (The Global Commission on the Economy and Climate 2018). A quarter of the world's population resides in countries with extremely high water stress, withdrawing over 80 percent of available surface and groundwater supply in an average year. Water crises have already threatened major cities from Cape Town to Chennai, and climate change is making things worse, especially in countries that are already vulnerable (WRI 2019a). At the same time, vast

[15] For example, the financing gap between what is needed to preserve biodiversity and ecosystems and what is actually spent on this purpose is over $700 billion a year (Deutz, et al. 2020).

[16] To cover about 34 percent of the land's surface, as opposed to current 15 percent, and 17 percent that are targeted by the Convention on Biological Diversity (https://www.cbd.int/).

amounts of wastewater – for example, over 80 percent in water-stressed Middle East and North Africa – are not reused, and often left untreated (World Bank 2018). Over four billion live without safely managed sanitation (The Global Commission on the Economy and Climate 2018). Investment in water-related infrastructure, and reducing water over-use are critical to making our economies sustainable and resilient, as well as to improving billions of lives.

- ***A circular industrial economy.*** Policies which encourage more circular, efficient use of materials could enhance global economic activity, as well as reduce waste and pollution. Shifting to a circular industrial economy, combined with increasing efficiency and electrification, including for hard-to-abate sectors and heavy transport, could decouple economic growth from material use[17] and drive decarbonisation of industrial activities (The Global Commission on the Economy and Climate 2018).

Infrastructure investment is central to accelerating the transformation (The Global Commission on the Economy and Climate 2018, IMF 2020). The next 10-15 years are critical, as the global economy will likely grow by a half and a billion more people will come to live in cities – requiring investment in the world's urban, land use, energy, and other systems of more than US$90 trillion. Locking such a vast amount of new investment in high-carbon assets would delay decarbonization by decades and make it progressively more expensive. The additional cost of investing in low-carbon infrastructure has been estimated at US$3-4 trillion, or about four percent of the total (The Global Commission on the Economy and Climate 2018), but this is now likely to be negligible given falling costs and as savings on operating costs can more than offset upfront investment costs. Moreover, there would be large associated benefits such as cleaner air, better health, less congestion and fruitful ecosystems.

Enabling the transformation and investment requires comprehensive and coordinated government-led climate action using a broad package of tools and policies (Stern and Stiglitz 2021). While pricing carbon and adopting ambitious emissions goals are essential parts of the package, climate action must be broader, as stopping emissions requires fundamental innovation, rapid diffusion of new technologies, and the reshaping of markets and socioeconomic systems (Victor et al. 2019). In addition to pricing carbon, the policy package includes fiscal instruments and regulations to incentivize circular economy and sustainable use of natural resources; public investment and industrial policies; policies to scale up and align finance with climate objectives and steer private investment toward climate-friendly assets; and policies to steer social norms and behaviors to a more sustainable and resilient consumption and business activity. For each policy area, a people-centered approach is needed to ensure long-lasting, inclusive growth and a just transition. We go through each policy area in more detail below.

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[17] A review of the evidence on decoupling finds that large, rapid absolute reductions of emissions requires sufficiency-oriented strategies and strict enforcement of absolute reduction targets (Haberl, et al. 2020).

IV. Climate Change Mitigation

A. Put a Price on Carbon

Pricing carbon is essential for mitigation.[18] If GHG emissions are free then there is no incentive to reduce them: the benefit accrues to the emitters – coal power plants, cement factories, drivers of gasoline cars, and many others – while the cost is borne by everyone. By contrast, if GHG emissions are costly, this sends a signal throughout the economy. Carbon-intensive goods become more expensive – an incentive to consume less of them, for example by saving energy, and to rebalance consumption patterns toward low-carbon goods and services. Carbon-intensive inputs also become more expensive for businesses, which incentivizes them to innovate and make their production processes more climate-friendly. Moreover, demand for low-carbon goods and services increases, and so does investment to expand their production. In the end, the price of carbon is a gauge that drives millions of decisions by multiple economic actors towards cutting GHG emissions and reaching mitigation goals in the most cost-effective way given individual and local circumstances.

Likely the most efficient instrument to a put price on carbon is a carbon tax (IMF 2019). It is essentially a charge on the carbon content of fossil fuels. For example, to produce one million btu[19] of energy one has to burn about 46 kg of coal, which would emit about 95 kg of carbon dioxide into the atmosphere. Alternatively, one could burn about 27 cubic meters of natural gas, which would release about 53 kg of carbon dioxide. [20] Or instead, one could entirely eliminate emissions by using, for example, solar panels or wind turbines. A carbon tax is also relatively simple to administer, as most governments can rely on the existing machinery of excise taxes. The carbon content of fossil fuels is stable, so there is no need to measure actual emissions.

An alternative to carbon taxes is an emission trading scheme (ETS), also known as cap-and-trade schemes. A typical ETS consists of the following sequence:

1) The government sets a medium-term goal for GHG emissions and draws a list of emitters who are obliged to participate in the scheme.

2) The government then allocates the corresponding amount of emission permits among the participating emitters.

3) Emitters are then required to hold enough permits to cover their emissions; and they can trade the permits with each other.

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[18] By "pricing carbon" we mean pricing all GHG emissions, not only those of carbon dioxide. Admittedly, as emissions of carbon dioxide constitute over three quarters of total GHG emissions, they attract most of the policy focus. Instruments to cut other emissions are less developed.

[19] Btu – British Therma Unit – a standard unit of measurement of energy. For comparison, one million btu is equivalent to burning about 33 liters of gasoline, e.g. running an average car for about 300-600 kilometers (depending on the fuel economy).

[20] Source: U.S. Energy Information Administration. These numbers are approximations.

In a world with perfect information, an ETS with auctioned emission permits would be equivalent to a carbon tax, but in practice there are differences. First, an ETS fixes the resulting amount of emissions but leaves the carbon price uncertain and volatile, which is bad for business planning. A carbon tax fixes the carbon price, but leaves the resulting emissions uncertain, so there is a risk that the mitigation target is not achieved. Both uncertainties can be mitigated, however: the carbon tax can be gradually adjusted to hit the emissions target, while an ETS can feature a minimal carbon price (a price floor) to reduce volatility. Second, an ETS is generally harder to administer than a carbon tax. The allocation of emission permits is less transparent than taxation. For example, a general feature of most ETSs is that some businesses get permits for free due to lobbying or competitiveness concerns. Besides, there are fixed costs to trading the permits and verifying the emissions, so ETSs usually cover only the largest emitters, and as a result their coverage of total emissions can be low. For example, the European Union's ETS – the largest in the world – covers only about 45 percent of the union's GHG emissions (EU 2020), so it needs to be complemented by carbon taxes in individual countries.[21] In smaller countries there may not be enough firms to create a viable trading market. Establishing a trading market may also be impractical for capacity-constrained countries.

The macroeconomic effects of a carbon tax and an ETS are similar. In the short term, a higher carbon price increases the price of carbon-intensive goods and services, most importantly energy – a production input for all businesses, and expenditure item for all households.[22] For a worldwide carbon tax of US$75 per ton of carbon dioxide electricity prices would on average go up by 43 percent, and gasoline prices by 14 percent (IMF 2019). As energy becomes more expensive, households and firms use it more efficiently, and so energy demand goes down. Total energy spending by businesses and households increases, however – crowding out other spending by households, and reducing businesses' before-wage profits. Businesses may in turn reduce investment, labor demand, and wages.

The direct dampening effect of energy prices on businesses' and households' energy demand is not the whole story, however. In the medium term, the effect can be offset by the productivity gains driven by low-carbon innovation, which is induced by a carbon tax (IMF 2020). The tax also yields revenues – up to five percent of GDP in some countries in the case of a US$75/ton tax (IMF 2019) – so the overall effect, and the acceptability of a carbon tax itself, – depend on how the government decides to recycle it (Chirloeu-Assouline 2015, Klenert et al. 2018). One option is to make the reform revenue-neutral[23] and to reduce other taxes. For instance, if labor income taxes decline, wages go up, and so does the labor supply. After-wage profits of businesses go up too, which may eventually lead to higher investment (IMF 2020). In this case, the overall effect of the carbon tax reform on economic activity may turn out to be positive – a so-called "double dividend" (supporting both climate change mitigation and the economy), as for example in Ireland (Conefrey, et al. 2013). More generally, consumption taxes,

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[21] There are examples of ETSs with better emissions coverage. For example, Californian ETS covers about 85 percent of state emissions (EDF 2020).

[22] The world on average spent about 6 percent of GDP on energy in 2014, based on energy use data from the World Bank World Development Indicators, and assuming the oil price of US$60 per barrel.

[23] Revenue-neutral means no changes to total government revenue.

carbon taxes being one of them, are considered to be less dampening for economic activity than income taxes (Acosta-Ormaechea, Sola and Yoo 2019).

There are other options to spend the carbon tax revenue. A "double dividend" is also possible if governments boost public investment or invest in health and education, especially in countries that need to make substantial progress towards the Sustainable Development Goals (Gaspar, et al. 2019). A "double dividend" may turn into a "triple" dividend if the public investment is also consistent with climate objectives. Likely less efficient but more politically feasible options to spend the revenue are distributing emission permits for free in an ETS, which would relieve the initial adverse impact on the emitters but may defeat the goal of emission reduction, or a universal dividend, which would essentially offset energy price increases for households. A more socially just and efficient policy is to introduce transfers that fall with income and take geographical disparities into account.

The effects of carbon taxes go beyond economic activity. Reducing the use of fossil fuels has important environmental and other co-benefits, which are not reflected in national accounts. Lower local air pollution is one. Coal burning and fossil fuel-based transportation are major air pollutants and health hazards, lowering the world's average life expectancy by over a year (Lelieveld, et al. 2020). Moreover, production and transportation of fossil fuels is prone to major environmental disasters, such as the 1989 Exxon Valdez oil spill in Alaska, or the 2010 explosion at the Deepwater Horizon offshore oil rig in the Gulf of Mexico. Other co-benefits of carbon taxes stem from reduced use of cars, the overwhelming majority of which still run on fossil fuels:[24] reduced congestion, fewer traffic accidents, and smaller road damages. In most countries the local co-benefits alone – that is, leaving aside the contribution to climate change mitigation – are enough to offset the potential dampening effect of carbon taxes on economic activity for a wide range of carbon prices (IMF 2019).

Despite its co-benefits and relatively mild macroeconomic effects, carbon pricing has yet to take off in most countries. As of end-2019, 58 carbon tax or ETS initiatives were active or scheduled for implementation around the world (Figure 4). Together these initiatives covered only 20 percent of global GHG emissions, although this number increased from less than five percent in 2010, and there are important ETS initiatives – notably in China and Germany – being launched in 2021. The effective carbon price varied from a few US dollars/ton in two dozen jurisdictions to US$119/ton in Sweden (as of 2021), resulting in a global average of just US$3/ton (accounting for non-taxed emissions) (World Bank 2019).[25] This is much lower than the US$50-100/ton that is needed to be on track for a 2°C warming scenario (Stern and Stiglitz 2017, IMF 2019).

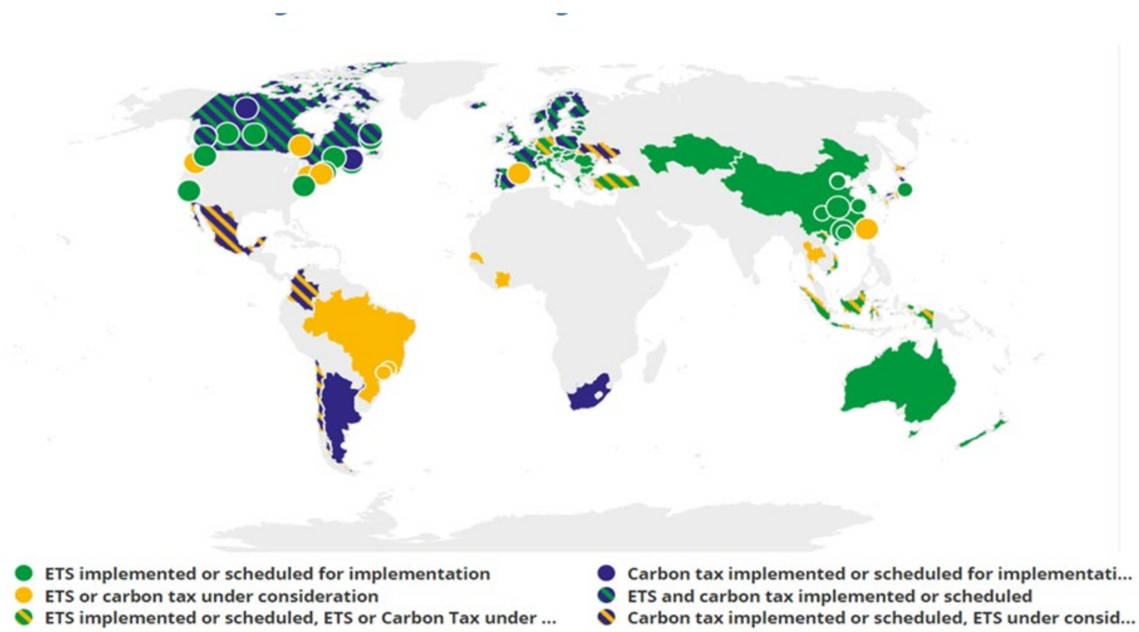
Aggravating the situation, many countries still subsidize fossil fuels-based energy, with annual total bill – accounting for co-benefits – estimated at around US$5 trillion, three quarters of which are due to domestic factors, meaning elimination of these subsidies is largely in

[24] As of 2018, despite significant growth, electric vehicles still constituted only about two percent of all newly sold passenger cars in the world (IEA 2019).

[25] The highest nominal carbon price also masks the fact that, across countries, many sectors are typically exempt from carbon taxes (Cullenward and Victor 2020).

countries' own national interest (Coady, et al. 2019). In the first half of 2020, G20 countries allocated at least $170 billion in public support for fossil fuel-intensive sectors as a response to the COVID-19 crisis (IISD 2020).

Figure 6. Carbon Pricing Policies around the World



Source: World Bank Carbon Pricing Dashboard, as of November 1, 2019.

In many countries carbon pricing and energy subsidy reforms were met with broad public opposition and eventually went off track. Households are worried about losing jobs and spending too much of their income on energy, which is especially important for the poor. Businesses are worried about competitiveness. Both are worried about inflation. All these concerns are valid and need to be addressed to make the reform socially just, politically acceptable, and inclusive. And success is not impossible: many countries and jurisdictions, starting with Finland in 1990, have been able to introduce and maintain a carbon tax, and many others were able to implement a sustainable and effective energy subsidy reform (for example, Brazil, Turkey, Namibia).

Successful reforms feature several common strategies (Clemens, et al. 2013, IMF 2019):

- *Inclusive decision-making*. Extensive consultations with all stakeholders about their concerns, the reform's objectives and expected outcomes.

- *Gradual approach* with tax increases scheduled well in advance – starting with lower taxes for those more exposed to international competition and on products more consumed by the poor (e.g. kerosene). Going gradual slows down inflation and buys time to affected stakeholders to adjust and to governments to demonstrate the benefits of the reform.

- *Efficient and equitable recycling of revenue*. Targeted measures for the most affected, especially the poor, are crucial. The poor typically spend more than the rich on energy products relative to their income (IMF 2019). Energy price increases can also spill over to prices of other essential goods. It is important to compensate the poor for the resulting reduction in their purchasing power. But the compensation does not have to cost much if it is well targeted, because in absolute terms the rich spend much more on energy products than the poor, so they benefit more from lower prices (IMF 2019, Clemens, et al. 2013).

  The measures can come in the form of means-tested direct transfers, in-kind transfers (e.g. more pro-poor spending on health, education or infrastructure), or tax subsidies (e.g. earned-income tax credits). A universal dividend – though less efficient than targeted measures – might be a more feasible yet still equitable option if government capacity is low, and simplicity of the reform is a priority (Klenert, et al. 2018).

  The revenue should also be used to smooth the transition for the most affected sectors and regions. The measures can come in form of retraining displaced workers or supporting their pensions, support for entrepreneurship, or region-specific targeted public investment.

Finally, carbon pricing strategy must take into account political economy factors. In some sectors, such as transport, consumers (and thus voters) may be very sensitive to price increases. In others, production may be concentrated in competitive, internationally-traded goods, and incumbent firms may be politically connected and able to block carbon pricing policies that increase firms' costs (Cullenward and Victor 2020). These political economy considerations may strengthen the case for sector-specific carbon pricing policies as well as non-price policies, to which we turn below.

B. Regulate and Set Standards

An important complement to carbon taxation is the direct regulation of GHG emissions or energy efficiency. For example, building energy codes, energy efficiency standards for appliances, and emission standards for cars are a commonplace in many countries (Evans, Roshchanka and Graham 2017). Regulation plays in favor of low carbon products (e.g. people purchase more energy-efficient goods), but it does not incentivize people to use the product less once it is purchased. However, the importance of regulation increases when the effect of taxation on emissions is uncertain, or the tax is simply too low for some industries for political reasons (Weitzman 1974, Mansur 2013). Also consumers of energy-intensive products often underestimate hard-to-assess future energy costs and give preference to easy-to-observe price discounts – a case of so-called "energy-cost myopia", which would cause producers to compete on prices at the expense of energy efficiency had there been no efficiency standards (Nordhaus 2013, Schleich, et al. 2019). Similar to carbon pricing, regulations and standards should come with financial incentives or government programs for the poor to enable them to comply. At the same time, it is important to remove regulations that create barriers to investment in low-carbon technologies, such as regulations that require the use of specific fuels for electric buses used in public transportation systems. International coordination can play an important role in setting expectations, for example by setting proximate dates for the phase-out of coal or internal combustion engines for road transport.[26]

Complementing and reinforcing regulations could be a system of feebates - revenue neutral sliding scales of fees on products/activities with above average emission rates and corresponding subsidies for products/activities with below average emission rates. Elements of feebates have already been integrated into vehicle tax systems in some European countries—but analogous instruments could be applied to other sectors (industry, power generation, heating for building, forestry) (IMF 2019).

C. Price Other Environmental "Goods" and "Bads"

Pricing and regulations are also the primary policy responses to other environmental issues. Some of them require corrective taxation (increasing price) of "bads", like in case with GHG emissions and climate change. Some could be better resolved by corrective subsidizing (decreasing price) of environmental "goods".

Forests, wetlands, and other ecosystems need to be protected and restored. Not only are they carbon sinks helping us with climate change, but they also shelter biodiversity, protect local climate, air, water, and soil, serve as a buffer against natural disasters, and provide recreational services. One way to protect them is to pay farmers and other landowners for their sustainable management and conservation. So-called payments for ecosystem services is an increasingly common practice in many countries at a national and local level (UNEP 2008, Bösch, Elsasser and Wunder 2019). At a global level, UN's REDD+ program aims to compensate developing counties for the carbon emissions that are offset due to sustainable forest management (UN 2020). Success of these programs depends on the details of their design: it is important, for example, to make sure that protection of some areas does not crowd-in deforestation in others, or that the payments for ecosystem services accrue to those who de-facto manage the forests and wetlands, in particular indigenous communities.

Regulations is an important instrument to protect ecosystems, especially where the payment schemes are less effective. For example, over 70 percent of forests are publicly owned (White and Martin 2002). Logging concessions must be regulated so that the harvesting rate is below the forest renewal rate, and some critical areas, like virgin forests[27] or habitats of endangered species, must be closed to logging altogether. Other ecosystems must be protected too, as this not only halts biodiversity loss, but also yields economic benefit. For example, strategically expanding just five percent of existing marine protection areas could improve future sustainable fish catch by 20 percent (Cabral, et al. 2020). At the same time, ecosystem conservation may run into conflict with the livelihoods of the poor, at least in the short run, and should thus be accompanied by mitigating measures. For example, Ol Pejeta Conservancy in Kenya runs multiple community projects around its borders, including conservation education, helping fund local schools, financial and technical assistance to local farmers, and managing

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[26] The UK and Japan for example have set dates of 2035 for ending new sales of cars with internal combustion engines. A dozen of other countries have announced a similar target. All of the major economies could align behind this target.

[27] Forest which have never been logged before.

human-wildlife conflicts.[28] Zambia's Community Markets for Conservation program teaches alternative livelihood skills to former wildlife poachers and supports local farmers, thus promoting conservation.[29] Many countries around the world compensate farmers for the damages caused by wildlife (Nyhus, et al. 2008).

Another important area to reform is how modern societies produce and consume food. The global food system is full of inequalities and inefficiencies: over eight hundred million people in the world are still malnourished, and at the same time around two billion are obese or overweight, and over a third of total food production is lost or wasted (The Global Commission on the Economy and Climate 2018). Intensive agriculture and agricultural expansion disrupts interactions with wildlife and increases contact among people, wildlife, livestock and their pathogens, which has led to almost all pandemics to date (IPBES 2020).

- ***Agricultural subsidies*** in 2016-18 were close to one percent of the world's GDP, contributing to inefficient use of water and chemical fertilizer, overgrazing, soil erosion, deforestation and loss of biodiversity. These subsidies ***must be reformed*** to fully reflect the social cost of food production, and to promote climate-smart agricultural practices, such as agroforestry, crop diversification, conservation of soil and water, local animal feed, and others – a sustainable way to increase agricultural yields and support subsistence farmers (FAO 2020).

- ***Sustainable and equitable allocation of water permits*** is especially important as over four billion people around the world are currently living in areas where demand of water outstrips supply, thus depleting reservoirs and aquifers (The Global Commission on the Economy and Climate 2018). Water subsidies are as much as 0.6 percent of the world's GDP contributing to its unsustainable use (IMF 2015).

- ***Sustainable wildlife harvesting*** is also a priority. Overfishing may be tackled through the sale and effective enforcement of fishing quotas, combined with regulation on fishing boats size, restrictions on harmful fishing methods, and protecting endangered species (World Ocean Review 2020). Similar principles apply to other wildlife.

- On the consumption side, a higher excise/sales tax on meat could be an efficient way to ***address higher social cost of livestock production*** compared to the plant-based food[30] (Godfray, et al. 2018).

Governments should also price chemical pollution and incentivize "circular economy" – an economic system aimed at eliminating waste and pollution, and keeping products and materials in use. Limiting air and water pollution can be done through corrective taxes, regulations, outright bans, or issuing emissions quotas, which can then be traded. Use of single-use plastic

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[28] https://www.olpejetaconservancy.org/community/

[29] https://itswild.org/

[30] Producing one calorie of beef, for example, requires about twenty five times more land, ten times more water, and emits twenty five more time GHGs than producing one calorie of pulses (Ranganathan, et al. 2016). In the United States, carbon footprint of a typical vegan diet is 85 percent lower than that of an average diet (Clark, et al. 2019).

can be reduced if governments ban it or charge a disposal fee. Plastic bag consumption in Ireland fell by 94 percent within weeks after the government introduced a plastic bag fee of 15 euro cents in 2002 – a practice followed by more than sixty countries since then (UNEP 2018). Incentives for "circular economy" can make production and consumption less resource intensive. These incentives include: taxes and subsidies to foster repair, sharing, resale, and remanufacturing; regulations to harmonize collection and sorting; fees and regulations to disincentivize landfilling and incineration and promote reuse and recycling (Ellen MacArthur Foundation 2021).

Pricing and regulations would only be effective if the rules are adhered to. Trust is of utmost importance here. Regulations are more likely to be followed if their rationale is well-explained to the public and if the public is inclined to cooperate and trusts government – which itself depends on how inclusive growth is. Sustainability begets inclusion, and inclusion begets sustainability. Compliance can also improve if the rules are simple and based on indicators that are easier to observe. Government's capacity to enforce can be strengthened by utilizing information technologies. Satellite imaging and remote sensing are now widely used, for example to track deforestation, e.g. by (Global Forest Watch 2020), water use, as for example in Turpan basin, China (World Bank 2017), illegal fishing (Imagesat International 2017), or air, water and soil pollution (Filippelli, et al. 2020) among others.

D. Accelerate Public Investment in Sustainable Infrastructure

Public investment speeds up the transition and enables investment in projects with low private returns but large environmental co-benefits, as is the case with many nature-based climate solutions. Public investment is also needed to coordinate and scale up private investment, even in the presence of a high carbon price. For example, renewable energy investment in remote areas requires high quality transmission grids. Discarding a gasoline car requires adequate substitutes for commuting. With large output and employment spillovers (or multipliers) to the rest of economy, low-carbon public investment is also an effective fiscal policy tool to boost economic activity (Hepburn, et al. 2020, Batini, et al. 2021).

A successful climate-friendly public investment strategy requires effective public finance management (PFM). Besides following the best general practices, governments should incorporate climate change considerations focusing on the entire PFM cycle - from macroeconomic analysis and planning to revenue, investment and spending management and policy – i.e., climate-responsive PFM (PEFA 2020). PFM practices should be aligned with climate objectives, as advocated in "Helsinki Principles" (The Coalition of Ministers for Climate Action 2019), for example by introducing climate-related procedures to evaluate performance of expenditure and taxes, and climate-related provisions in regulatory framework for public investment or procurement (Schwartz, et al. 2020). Fiscal rules may have to be aligned with climate objectives.

E. Scale Up and Align Finance with Climate Objectives

Reforming finance and ensuring that it enables—rather than hinders—deep decarbonization is critical for the transition to inclusive, resilient and sustainable growth, for several reasons:[31]

- ***Incomplete knowledge and risk, and capital market failures.*** Without appropriate policies, there is a wide gap between the social and private return to green investments (Stern and Stiglitz 2021). Private investors have generally elevated perceptions of the risks of green investments because of uncertainties about future climate policies and carbon prices, ability of these projects to deliver carbon abatement, as well as these projects' high upfront capital costs and relative lack of technological maturity, not least due to lack of historical data on which to base investment decisions, and generally lower degree of liquidity (Nelson and Shrimali 2014). As a result, investors tend to view expected return on low-carbon projects as too low given perceived risks. Likewise, the expected private return to carbon-intensive projects could be too high if financial climate-related risks are not properly regulated.

- ***Short-termism.*** Climate risk stems from a "tragedy of the horizon": catastrophic effects of climate change will be felt beyond the traditional horizons of market participants and most decision-makers, which extends only a few years (Carney 2015). Without adequate policies, financial asset prices will not reflect the long-term benefits of climate change mitigation. Moreover, governance problems and interactions between the financial system, regulation and accounting standards can amplify short-termism in finance, hindering the financing of long-term green investments.

- ***Lack of transparency about exposure to climate risks.*** Even if desired, rebalancing of investment portfolio from polluting (carbon-intensive) to green investments would be inhibited in absence of clear information (taxonomy) about which assets are polluting or green.

- ***Network and coordination externalities.*** Addressing climate change involves major structural changes in core systems of the economy: energy, land, cities, transportation, industrial supply chains. These changes require complex coordination, which goes beyond carbon pricing, especially in the presence of multiple market failures (Stern and Stiglitz 2021). In particular, several sectors are characterized by a low elasticity of emissions to carbon prices (Rafaty, Dolphin and Pretis 2020). This is notably the case in sectors that face structural challenges, including urban systems, industrial supply chains, and production networks (Hepburn, Stern and Stiglitz 2020).

- ***Knowledge spillovers.*** These typically occur when investors are unable to capture the full return on their R&D investments into low-carbon technologies (Acemoglu, et al. 2012).

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[31] Finance's role in climate policy is emphasized in Article 2 of the Paris Agreement, which calls for "making finance flows consistent with a pathway towards low greenhouse gas emissions and climate-resilient development" (UNFCCC 2020).

- ***Unpriced co-benefits of climate change mitigation and adaptation.*** Actions that help society mitigate and adapt to climate change have many potential co-benefits that are not priced by markets. Co-benefits include lower pollution and congestion, the protection of ecosystems, access to energy, and faster technological progress.

- ***Weak carbon price signal.*** In a context of regulatory uncertainty, a large drop in the price of fossil fuels—which tend to be quite volatile—can more than offset the price signal sent by a carbon tax. In addition, most sectors are still at early stages of decarbonization, in which key technologies and low-carbon firms are nascent – in contrast to incumbent carbon-intensive firms (Energy Transitions Commission 2020, Aklin and Mildenberger 2020). At the same time, price signals work best by driving optimization of emission reduction when technologies are commercially mature. For this reason, it is important to complement carbon pricing with financial sector and other policies to ensure early redirection of investment to low-carbon technologies and firms that are viewed as risky – for example because the carbon price signal is seen as volatile and unreliable for investment decisions (Cullenward and Victor 2020).

Political economy factors, such as lack of political acceptability of carbon taxes, also play an import role.

Taken together, these market failures and political economy factors lead to a lack of financing of green projects, and a socially undesirable level of financing of polluting activities. This is especially the case in developing and emerging economies, which are characterized by high transaction costs in unstable institutional contexts, meaning that fossil fuels—which benefit from lower upfront capital costs and are perceived as less risky than low-carbon projects—are favored in investment decisions (Hirth and Steckel 2016). The global financial system continues to be unaligned with climate objectives. In 2019, the largest 33 banks allocated about $650 billion to fossil fuel projects (WRI 2019). In addition, equity valuations across countries do not reflect projected incidence of climate physical and transition risks (IMF 2020a).

The inadequacy of finance is also reflected in the misalignment of global capital flows between regions and sectors with abundant liquidity and regions and sectors that are relevant to climate-transition investments but cannot obtain capital. This leads to a paradox: trillions of dollars in savings in high-income economies earn a negative real interest rate, while $11-23 trillion in climate-smart investment opportunities in emerging-market and developing economies are not being financed (Green Climate Fund 2020).

Aligning financial system with climate objectives is the primary goal of The Network of Central Banks and Supervisors for Greening the Financial System (NGFS)), the Coalition of Finance Ministers on Climate Action, and COP26 Private Finance Agenda.[32] The next section outlines the policy options.

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[32] https://www.ngfs.net/en and https://www.bankofengland.co.uk/events/2020/february/cop26-private-finance-agenda-launch

Financial and Monetary Policies for Climate Change Mitigation and Adaptation

The role of financial and monetary policies in the fight against climate change is fourfold. First, managing the financial stability risks posed by climate change. Second, closing the gap between the social and private returns to green investment. Third, mobilizing resources for investment in resilience to climate change. Fourth, making supervisory and monetary policies consistent with net-zero emission objectives.

Managing the financial stability risks posed by climate change

There are three main types of climate risks: physical, transition and legal risks (Carney 2015). Physical risks arise from climate hazards and longer-term shifts in climate patterns. Transition risks stem from the process of structural change in the transition to a low-carbon economy, including changes in climate policies, technologies, consumer behavior and investor preferences. Legal risks relate to firms' fiduciary responsibilities. A major transition risk is that high-emission financial assets could rapidly lose value and become "stranded" as more ambitious climate policies are implemented worldwide.[33] These risks are of a systemic nature, in that they can potentially affect the entire economy and financial system. Some estimates suggest that stranded fossil fuel assets could reach US$12 trillion by 2035 (The Global Commission on the Economy and Climate 2018). Abrupt asset price corrections have already happened: for example, over two dozen coal companies in the U.S. went bankrupt in 2012-15, and many others lost over 80 percent of their share value as a result of the energy mix shifting towards renewables and natural gas (Carbon Tracker Initiative 2015).

Three broad types of financial and monetary policy instruments should be used to manage climate-related financial risks (Krogsrup and Oman 2019). First, those that redress the underpricing and lack of transparency around climate-related financial risks. Second, those that reduce the short-term bias in the financial sector. Third, those that seek to reflect climate risks in macroprudential policies (policies aimed at safeguarding the financial system).

The first category involves gathering high-quality climate-related financial data, introducing mandatory climate-related financial risk disclosures (regarding both physical and transition risks) by firms and financial institutions, conducting climate-related stress tests of financial institutions and financial systems. The first step is developing a public taxonomy of environmentally unsustainable assets. The taxonomy should be official rather than private, and discussions over its content should be shielded from lobbying efforts, in order to prevent greenwashing by financial firms – i.e., convincing markets and regulatory authorities that carbon-intensive or polluting activities are "green." Jurisdictions that have embarked on this effort should finalize their taxonomy, but ultimately international coordination will be required to avoid regulatory arbitrage and other issues that will inevitably arise. The Financial Stability Board's Task-Force on Climate-related Financial Disclosures Disclosures (TCFD)[34] is an important step in this direction, but net-zero considerations (including the concept of "double materiality,"

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[33] According to the ECB, climate risks are firmly embedded in advanced economies' economic structures, with about 40 percent and 32 percent of jobs in the euro area and the United States, respectively, being in carbon-intensive sectors (Schnabel 2020).

[34] https://www.fsb-tcfd.org/

discussed below) need to be put at the center of TCFD recommendations, in order to make the TCFD framework consistent with net-zero prudential policy (Robins, Dikau and Volz 2021). Moreover, international standard-setting bodies should establish sustainability reporting standards boards, as the International Financial Reporting Standards (IFRS) Foundation is contemplating in the context of COP26.[35]

The second category includes prudential and corporate governance reforms to reduce the role of short-term shareholder value maximization in firms' behavior and strategies. An example is corporate accounting according to the CARE (Comprehensive Accounting in Respect of Ecology) model, which incorporates social and environmental issues into firms' balance sheets and income statements, extends financial solvency to environmental and social solvency, and extends the principles of protection of financial capital to the protection of natural and social capitals (Admati 2017, Rambaud and Feger 2020).

The third category is strengthening risk management by Central Banks and financial institutions, and includes liquidity and capital requirements and sectoral capital buffers targeting credit to climate-exposed sectors. Central banks must also ensure that their collateral frameworks fully reflect climate risks.

Closing the gap between the social and private returns to green investment

The main policies are of two kinds. First, macroprudential regulations, including a surcharge on environmental unsustainable assets in banks' capital requirements. Second, de-risking and incentives for green private investment: loan guarantees and subsidies, feed-in tariffs with transparent phase-out horizon, risk guarantees (e.g. first-loss capital). [36] While de-risking measures can increase green private investment, frameworks must be developed to assess and monitor related fiscal risks and costs, notably ensuring the transparency of direct and contingent long-term public liabilities (Eyraud et al. 2021, Gabor 2021). Monetary policy, notably central bank exclusion of carbon-intensive assets, would also increase the capital cost of polluting investments. Central banks could also purchase low-carbon project bonds. Such bonds should be issued, following corresponding mandate changes if necessary, by national or regional development banks.[37]

A further instrument is creating new low-carbon financial assets with embedded notional/shadow carbon prices—for example, carbon remediation assets. Value of such assets would depend on amount of GHG emissions they help avoid at a predetermined notional/shadow price (Aglietta, Espagne and Fabert 2015, IPCC 2018).

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[35] In particular, it is critical to harmonize international carbon accounting norms – especially with respect to the definition of "net-zero" emissions at the global and national level, as well as at the level of individual financial institutions, firms and other organizations. "Net-zero emissions" should be defined in absolute terms, not by subtracting so-called "avoided emissions" from actual emissions. On the challenge of converging toward more-standardized sustainability reporting, see Ferreira et al. (2021).

[36] First-loss capital refers to arrangement by which an investor or grant-maker agrees to bear first losses in an investment in order to crowd-in co-investors.

[37] There is evidence of significant carbon intensity in the portfolio of financial assets bought by the Bank of England and the European Central Bank (Matikainen, Campiglio and Zenghelis 2017).

Mobilizing the resources for investment

Central for developing countries' ability to make progress on mitigation and adaption is to develop domestic and international financial sources and capital flows from the geographies where the savings are, to the geographies and sectors where the investments for the climate transition are. Financing the large upfront resources that will be needed for climate and development transitions will be challenging for several reasons. First, all countries, but especially emerging markets and developing countries, are facing much more difficult debt and fiscal constraints as a result of the pandemic. Second, while investments in sustainable infrastructure yield strong economic benefits, these returns are typically realized over a long time period and often difficult to capture for private investors because of large spillovers. Third, while there are abundant pools of long-term savings, and interest rates in international markets are at exceptionally low levels, many emerging markets and most developing countries find it difficult to access long-term finance and the cost of capital is a major impediment for scaling up sustainable investments.

Boosting international climate finance is essential to coordinated and effective global climate action, especially in times when most developing countries are devastated by the COVID-19 pandemic (Stern 2020). Some estimates project that the low-carbon infrastructure investment gap in developing countries could reach $15-30 trillion by 2040 (Green Climate Fund 2020). A key pillar of the Paris Agreement is the pledge by developed countries to jointly mobilize US$100 billion per year to address the needs of developing countries. Yet, this pledge is unlikely to be met in 2020 (Independent Experts Group on Climate Finance 2020). Developed countries must deliver on the commitment to mobilize $100 billion in climate finance a year in 2021 and build on that to expand international public climate finance prior to 2025 when the next target will be set. Because of their mandates, instruments, and financial structures, multilateral development banks (MDBs) are the most effective international means to support enhanced climate action in developing countries and for mobilizing and leveraging climate finance at scale. There is also great scope and need for mobilizing private finance at scale through better public-private partnership to unlock investments, mitigate risks and create new asset classes attractive to long-term institutional investors.

Mobilizing the resources for green investment in developing countries would contribute to both climate change mitigation and reducing global and local inequalities. For example, an $800 million private investment in the Lake Turkana wind power plant in Kenya was enabled by partial risk guarantees (capped at $24 million) and technical assistance by the African Development Bank. The plant produces seventeen percent of the country's total electricity supply, supports over three hundred local jobs, and is projected to yield $35 million of tax revenue annually (LTWP 2019).

At the global level, proposals have been made to reshape the international monetary system to mobilize considerable resources for climate resilience. One proposal is to use the IMF's Special Drawing Rights (SDRs) to fund the paid-in capital of the Green Climate Fund (Bredencamp and Pattillo 2010). Another proposal is to create a substitution account at the IMF in order for central banks and governments with excess international foreign exchange reserves to deposit them at the IMF in exchange for SDRs (Aglietta and Espagne 2018). These SDRs could be lent to developing countries when market conditions become adverse, so that these countries can continue to finance their development policies—notably their climate policies. The IMF would thus play its role of lender of last resort in the international monetary and financial system. Countries with excess SDRs could also lend them to multilateral development banks, which could in turn finance investments required to meet Paris Agreement emission reduction pledges.

Making monetary and supervisory policies coherent with net-zero emission objectives

Central banks and financial supervisors need to ensure that their activities are coherent with net-zero government policy. One basic reason for this is that the impact of climate change could be of a similar magnitude to some of the most disruptive events in the 20th century, and therefore pose a significant threat to price stability (van Tilburg and Simić 2021). Central banks' and supervisors' policy frameworks should follow a "double materiality" approach that relies on an assessment of both the impact of climate change on financial institutions and financial institutions' impact on climate change. [38] Three priorities for central banks' and supervisors' role in climate policy stand out (Robins, Dikau and Volz 2021). First signaling the evolution of their climate strategies in order to foster the alignment of financial institutions with net-zero over the long term. Second, liaising with governments – who give central banks their mandate – in meeting net-zero goals, so as to transition at the needed speed and scale while maintaining financial and macroeconomic stability.[39] Third, ensuring that central banks' monetary operations and portfolios are consistent with the goals of the Paris Agreement (Villeroy de Galhau 2021).

Among these priorities, a concrete proposal to ensure the coherence of monetary policy with net zero is for the central bank to purchase low-carbon project bonds issued by a public investment or development bank (De Grauwe 2019). To remedy the dearth of net-zero-aligned collateral (Oustry, et al. 2020), public investment banks could emit large amounts of long-term, low-carbon bonds, with a high proportion purchased by the central bank as a non-competitive bidder.

More generally, central banks should coordinate their actions with other actors, notably governments, the private sector, civil society and the international community, and consider green monetary-fiscal-prudential coordination (Bolton, et al. 2020). It is essential that policy frameworks follow a "double materiality" approach, in which reducing the impact of the financial system on the climate system is part and parcel of a robust risk-management strategy (see Oman and Svartzman 2021).

F. Support Climate-Friendly Innovation

Innovation is key to sustainable growth. Achieving socio-economic progress without depleting our natural wealth is only possible if societies learn to use this wealth sustainably from

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[38] ECB Executive Board member Isabel Schnabel has stressed that central banks' actions should not "reinforce market failures that threaten to slow down the decarbonization objectives of the global community" (Schnabel 2020). See also Oman and Svartzman (2021).

[39] For example, by ensuring that supervisory policy requires financial institutions to submit net-zero transition plans (Caldecott 2020, Robins 2020).

an ecological perspective.[40] Innovation is even more important for the transition to sustainable growth, as the global economy needs a push to switch from traditional and well-established industrial processes and consumption patterns to new and unexplored ones. Energy and technological systems' inertia pose a significant challenge to this transition.

Government policies have traditionally been key in enabling innovation and structural change. Ideas are free to share and use once they are out, but producing them is costly, and not all of them turn out useful. This creates a strong case to subsidize innovation, and many governments are doing it, especially for basic research.

With climate change mitigation, the role of government is even more important, as private returns to innovation in this area can be very low. For example, without carbon tax, the private return to carbon capture and storage for coal power plants is essentially negative – this technology does not make the plants more productive or efficient. The social return to this technology is high though: it helps remove carbon from the atmosphere, and so making this technology cheaper and scalable in the medium run is likely necessary to get us to net zero emissions by the midcentury. In addition, there is a strong case for governments to not only promote basic research, but also to turn such research into viable business products and bringing them to the market, thus overcoming the so-called "innovation death valley" (Grubb, Hourcade and Neuhoff 2014).

Policy instruments to support innovation include:

- *Incentives for private climate-friendly innovation:* de-risking (e.g. loan guarantees, feed-in tariffs[41] with transparent phase-out horizon, public procurement to guarantee initial demand for new products and services), inward investment promotion, R&D tax deductions and credits.

- *Public funding of climate-friendly innovation:* strategic investment funds, funding centers of expertise, funding of universities and research institutes, grants for basic research, including sustainable innovation contests; spending on education and job training in climate-friendly industries.

- *Public wealth funds:* public equity investments can give direction and confidence for investments in industries of the future. State investment banks can likewise be critical by providing patient capital to support "mission-oriented" innovation and investment (Mazzucato and Penna 2016, Detter, Fölster and Ryan-Collins 2020).

Applying these policy instruments must be accompanied by frameworks to monitor and assess fiscal risks, as well as by following the best governance practices for state-led innovation policy

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[40] For example, as (Pimentel and Pimentel 2008) show, while the mechanization of agriculture boosted agricultural productivity defined in the traditional economic sense, it resulted in a decline in energy yield, with more calories of energy being required to produce a calorie of food.

[41] A feed-in tariff is a price for generated electricity that is fixed for producers at a lower than market price level, whereas the difference between the market price and the tariff is paid by government.

(Aiginger and Rodrik 2020, Cherif and Hasanov 2019, IMF Forthcoming). Policies like aligning finance with climate objectives and pricing carbon are essential too.

Climate-friendly innovation already shows a remarkable progress. The shared direction of travel since the Paris Agreement has given impetus for companies to invest and innovate, and for the markets for zero-carbon solutions to start scaling – from electric vehicles to alternative proteins to sustainable aviation fuels. For example:

- By 2030, low-carbon solutions could be competitive in sectors accounting for nearly three-quarters of emissions; this is up from one-quarter today (electricity) and no sectors five years ago (SYSTEMIQ 2020).

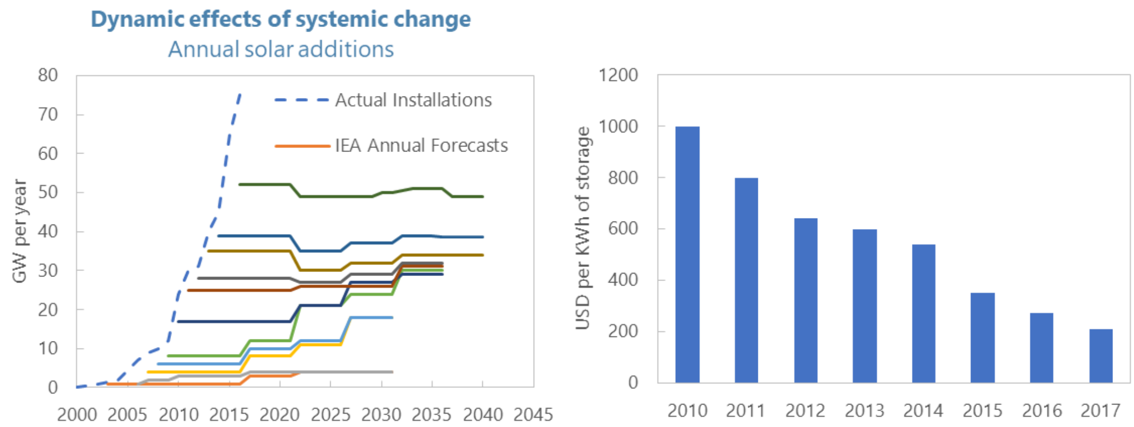
- Each year since 2000 the world has been adding more solar power generation capacity than the year before – significantly outpacing the market forecasts (Figure 7). The prices of photovoltaic panels and storage per unit of energy went down by four times since 2010 (Figure 7). The initial demand for the storage and new installments likely came from subsidies and feed-in tariffs notably in Germany, China, U.S. and U.K., but the current dynamics is mainly driven by the rapid increase in efficiency of the energy production and corresponding decrease in prices.

- The first contracts for offshore wind in the U.K. in 2014 were awarded at feed-in tariffs of 140-150 pounds per megawatt-hour – about three times the wholesale electricity price at that time. In 2019, in the new round of auctions, the feed-in tariffs went down to 40-45 pounds per megawatt-hour, beating even the most optimistic forecasts. Offshore wind in the U.K. is expected to be subsidy-free by 2023 (Evans 2019). [42]

This progress suggests that a carbon-free energy future is viable. The comparison with the market forecasts, however, shows that private actors and policymakers may underestimate potential returns to climate-friendly technologies, so they may underinvest in them in the absence of bold government action.

[42] By 2030, low-carbon solutions could be competitive in sectors accounting for nearly three-quarters of emissions; this is up from one-quarter today (electricity) and no sectors five years ago (SYSTEMIQ 2020).

Figure 7. Solar Energy Deployment and Price: Far Better than Expected



Sources: BloombergNEF

G. Provide Nudges and Information to Change Social Values

Separately from policies that aim to change relative prices, policies should steer social values and norms toward sustainable consumption and investment choices. Low energy demand and low demand for land- and GHG-intensive goods are key to achieving the 1.5°C goal (IPCC 2018). In this vein, providing education and clear and accessible information on climate change, its risks, and ways to tackle it is an essential complement to carbon pricing and financial incentives. Examples include:

- *Requiring labelling and certification that reflect the carbon and ecological footprint of goods or services* being sold or advertised: regulations requiring labelling of appliances, cars, and buildings by energy efficiency; information on carbon footprint of goods and services (e.g. flights) in their sales and advertisement; standardized food labelling to reduce the consumer confusion about the food safety, and hence waste.

- *Government support for independent certification of sustainable practices*: for example, Forest Stewardship Council for forests, Marine Stewardship Council for fisheries, or Roundtable on Sustainable Palm Oil for palm oil.

- *Mandatory disclosure of climate-related risks by businesses* – to inform potential investors.

- *Education and information campaigns* are essential. Research by McKinsey&Company shows that many technologies existing today, especially in agriculture and energy efficiency, not only reduce GHG emissions, but also yield positive return on investment even if the carbon price is zero (McKinsey&Company 2009). Yet, they are not fully utilized. For many households and businesses adoption of these technologies, the "smart" choice, is a matter of education and awareness.

  Education can serve to promote both mitigation and inclusion. For example, the FairWild

Standard initiative[43] works with local communities around the world – mostly subsistence farmers – to promote the sustainable harvesting of wild plants while developing viable business models.

- Mandatory work-at-home (WAH) policies during the COVID-19 pandemic, complemented by technological solutions that made the WAH feasible, could lead to a permanent shift in preference to work at home, which would reduce commuting and business travel, and hence decrease GHG emissions.

H. Cooperate Internationally

No single country can resolve the climate change crisis alone. Getting to net zero GHG emissions by the midcentury means everyone must participate, and acting together is larger than the sum of individual actions (Bhattacharya and Stern 2020).[44] By acting together, the world will benefit from stronger demand expansion and investment recovery, economies of scale, learning by doing, lower costs for new technologies and the necessary collective actions on climate and biodiversity that are urgently needed. Global cooperation is crucial.

While global issues like climate change would be best resolved by a global government, at present cooperation among national governments is done via international agreements. Signing (and implementing) one is a voluntary action, but they do serve as a mechanism of moral suasion and, importantly, accounting for progress and effort that each country puts in towards global good. Not every agreement turns out effective, but there are many examples of success. The Montreal Protocol of 1987 phased-out the use of ozone-depleting substances called chlorofluorocarbons (CFCs) and effectively stabilized the ozone levels in the stratosphere, even though the full recovery is yet to be observed (Solomon 2019). Effectiveness of the Paris Agreement on climate change is yet to be assessed, but it could serve as a useful international framework for cooperation.

Some countries may freeride on international commitments to gain competitiveness in carbon-intensive sectors against those countries, which cooperate. The freeriders effectively miss out on opportunities to gain competitiveness in emerging low-carbon sectors. But the result of the freeriding is that global GHG emissions may not decline but rather "leak" to the jurisdictions with laxer rules. One way to mitigate the freeriding problem is to implement an international carbon price floor – world-wide, regional, or among large emitters. A relatively small carbon price would be a politically feasible complement to other mitigation policies, and at the same time it would not affect international competitiveness if implemented by all parties (IMF 2019). Freeriding in carbon-intensive trade-exposed sectors could also be deterred by border carbon adjustment - essentially a tax on the carbon content of imports if carbon price is too low in the country of origin(Condon and Ignaciuk 2013). For climate-induced trade restrictions to work as intended, however, it is essential to establish clear rules and procedures, in particular on quantifying the carbon content of imported goods and on computing the effective carbon price in the country of origin. Without the clear rules in place the risk is that such trade restrictions would turn into a political tool to protect industries from international

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[43] https://www.fairwild.org/

[44] For example, government spending multipliers are larger if they are coordinated internationally.

competition rather than induce climate action. It is also important to support the transition to zero-carbon for low-income country producers and exporters through technology transfer and finance.

Free trade agreements and other existing international treaties must also be aligned with countries' climate objectives. For example, the EU-Mercosur free trade agreement gives Brazil, Argentina, Paraguay and Uruguay access to the EU single market for sugar, ethanol, poultry and beef. This raises questions on the agreement's compatibility with EU emission reduction objectives, as livestock farming accounts for 80 percent of deforestation in Brazil, implying significant imported emissions (Global Forest Atlas 2021).[45]

Another important area for cooperation is international climate finance, which is discussed in detail in Section III.E above.

V. Building Resilience and Adaptation

Some damage from climate change cannot be undone even with the strongest mitigation effort. The planet is warming, the sea level is rising, the frequency and magnitude of natural disasters are increasing. We need to learn to live with these changes, adapt to them, and minimize their adverse impact on our well-being.

In addition to physical risks stemming from climate change, we also need to adapt to risks stemming from the transition to a low-carbon economy. Carbon-intensive industries will shrink, which means workers and capital will need to be retired or reallocated, and some of them may become "stranded": once a coal power plant is built, it is hard to repurpose it for something else. Financial stability can be at risk too. An additional risk for fossil-fuel exporters is that shrinking fossil fuel demand will mean a significant shortfall in government revenue and a deterioration in the trade balance (UNCTAD 2019). The policy challenges posed by the transition risks are similar to those posed by other sources of structural transformation, such as automation or globalization.[46] Nevertheless, dealing with these risks and making sure that the transition is socially just are key to the success of climate change mitigation.

It is important to understand that mitigation is necessary, despite the existence of transition risks. Our ability to adapt even to moderate temperature shocks is quite limited (Dell, Jones and Olken 2012) – whether due to habit persistence, financial constraints or technological feasibility. The cost of the adaptation and the list of actions to do often turn out larger than initially thought. For example, U.S. city Miami ranks number one in the world by the value of assets exposed to the sea level rise (Hallegate, et al. 2013). Protecting these assets seems like a worthwhile investment, but simply building a seawall around them will not help. The city sits on porous limestone rock, so the raising water would bypass the seawall and come through the ground below - threatening not only the city's expensive properties, but also its main sources of freshwater supply (High Water Line 2020). Adaptation quickly becomes prohibitively expensive

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[45] Despite the reforestation efforts at home, G7 countries continue to contribute to global forest loss due to international trade in goods causing deforestation in their trading partners (Hoang and Kanemoto 2021).

[46] Automation of mining operations is expected to replace 30-70 percent of jobs in the industry over the next decade (Cosbey, et al. 2016).

as we move up the ladder of projected average global temperatures – even half a degree makes a sizeable difference, and damages increase non-linearly (IPCC 2018). And if we go above 2°C and trigger the chain of catastrophic risks, it would be virtually impossible to adapt without a drastic drop in our welfare or technological advances, which seem unfeasible at present. For example, humanity is not capable of reversing biodiversity loss, and even conservation of existing threatened species can often be an insurmountable challenge. In 2001, Andalas was the first Sumatran rhino born in captivity in more than one hundred years. Despite this success and despite decades of conservation efforts, the species that once roamed the forests from China to Indonesia is still on the brink of extinction (Sumatran Rhino Rescue 2020). Mitigation of climate change is therefore a priority: staying within 2°C of global warming minimizes the change of catastrophic risks and enables us to adapt to the changes at a reasonable cost.

The good news is that many mitigation policies are helpful for the adaptation too. Ultimately, the cheapest and most effective way to adapt is climate change mitigation. In the financial sector, disclosure and prudential regulation of transition and physical climate change risks not only helps steer investors to green assets, but also induces them to accumulate sufficient capital buffers to withstand the risks that are already in their portfolio. Restored wetlands and forests not only serve as carbon sinks, but also absorb storm surges and smooth wind and temperature fluctuations. Decentralized wind and solar power production and storage (for example, in form of an electric vehicle battery) not only emit zero GHGs into atmosphere, but also provide uninterrupted electricity supply in times when electricity grids are damaged by a natural disaster. Agroforestry and crop diversification not only make for a more climate-friendly land use, but also make food supply less sensitive to climatic shocks.

Many policy instruments used for mitigation are applicable, and in fact essential for, adaptation. Adaptation is less ridden with market failures than mitigation – reducing GHG emissions benefits the world, but the benefit of building a storm-resistant house is private. There is still a lot of space for active government involvement, however. Whether the issue at hand is an imminent natural disaster or longer-term gradual change, individuals and businesses are often uninformed about the climate risks they face. When these risks materialize, coordination and cooperation among different actors are essential. Insurance against risks is riddled with information externalities, and often needs to be mandated or subsidized. Investing in adaptation is in people's private interest, but those who underinvest may inflict damage on others: a storm-resistant house may withstand strong winds, but not another non-fortified house falling on it. Investment may also be lower because of financial constraints, land tenure issues and misaligned landlord-tenant incentives. It therefore makes sense to subsidize or regulate private investment for adaptation. The role of public investment is important too: building individual storm-resistant houses helps, but investing in, for example, coastal forests may provide a safety cushion for everybody.

To build resilience and adapt to climate change, governments should focus on two broad objectives (IMF 2017).

The first is to enhance society's ability to smooth the impact of climatic shocks and to transform structurally in case the shocks are longer-term or permanent. If a hurricane destroys fisheries or tourism infrastructure on a coast, those involved in these industries need to be able to start all over again or move inland to find other another activity. If climatic conditions become unsuitable to grow traditional crops, farmers need to be able to explore new more resistant varieties or find sources of income beyond agriculture. Structural change (transformations) like those above are never easy, especially for the poor, and the role of governments is to minimize the burden by properly regulating product markets, promoting financial inclusion, supporting entrepreneurship, and importantly, helping the displaced workers retrain and find new jobs. Equally important is to have policies and resources in place to minimize and smooth the initial impact of a shock.

The second objective is to reduce exposure and vulnerability to climatic shocks. Helping victims of a hurricane is paramount, but they may need less help if their houses are hurricane-proof, the hurricane warning comes well in advance, and there is a clearly communicated evacuation plan. Crop failure insurance helps smooth the cost of a draught, but its premia may become more affordable if farmers use more weather-resistant agricultural technologies. Very often the damage from climatic shocks is irreversible – human lives are lost – and so it is important to prepare for these shocks in advance rather than deal with their aftermath. The key policies to increase resilience are providing information, e.g. early warning systems for natural disasters, encouraging and mandating private investment in resilience, and investing in resilient infrastructure.

Below we discuss the policies needed to progress on each of these two objectives.

A. Smooth Impact of Shocks and Ease Adjustment to the Permanent Ones

To adjust to climate shocks and to smooth their impact, countries need well-functioning macroeconomic and structural policies.

Maintaining macroeconomic stability is key. Climate shocks have immediate adverse effects on economic output and employment and may hurt the economy further through a deterioration in confidence, uncertainty, financial instability, inflation or deflation, and external imbalances. To reduce the damage and prop up internal and external demand, governments should employ a set of counter-cyclical macroeconomic policies: accommodative monetary policy – through reduced interest rates, depreciated exchange rate, asset purchases – and expansionary fiscal policy – through well-targeted social safety nets, unemployment benefits, a reduced tax burden, and discretionary actions, such as public investment.

For the economy to be able to smooth climate shocks, it is important to maintain the buffers. Low and stable inflation gives space for accommodative monetary policy when needed. Sustainable public debt is key for the government to be able to deploy expansionary fiscal policy (Stern and Zenghelis 2021). Private savings by households and firms serve a cushion beyond the government assistance, and financial institutions should provide possibilities to save that are suitable for everyone, even for the poorest. Financial institutions also need to maintain sufficient capital buffers against climatic shocks.

Climate change should be explicitly taken into account when projecting the size of the needed buffers. Banks should be required to disclose climate-related risks, whether stemming from potential physical damage or transition to the low-carbon economy, and the banking stress-tests by financial authorities should explicitly wage the effect of large but plausible climatic shocks on the financial stability. Considerations about the fiscal space and the appropriate level of public debt should also account for the potential government spending in case of a large but plausible natural disaster. Assessing the impact of climate shocks on public debt sustainability at a 20- or 30-year horizon is key. Exporters of hydrocarbons should create extra fiscal space to compensate for potential loss of government revenue during the transition to a low-carbon economy.

An alternative and often a complement to maintaining the buffers is buying insurance (Mills 2005). Examples are individual insurances against floods, forest fires, crop failure among others, and inter-governmental initiatives, such as African Risk Capacity (ARC), Pacific Catastrophe Risk Assessment and Financing Initiative (PCRAFI), or Caribbean Catastrophe Risk Insurance Facility (CCRIF), which offer countries possibility to insure themselves against large natural disasters. As opposed to maintaining buffers, insurance requires smaller upfront cost,[47] and it can provide quicker and more efficient access to the funds when they are most needed. However, fast-evolving and uncertain nature of these disasters due to climate change leads to large precautionary insurance premia, which combined with financial constraints often results in low or no coverage for the poorest – those who need the insurance the most. For example, only 6.2 percent of farmers in Sub-Saharan Africa and South Asia purchased insurance against climate risks in 2011 (GIZ 2016). Even in high-income German state Bavaria only 41 percent of residents in high-flood risk areas can afford to buy the insurance (Rodriguez Martinez, Büsing and Leistner 2020). In some cases it makes sense to subsidize the insurance for the most vulnerable, or for lower-income countries, for example through the World Bank's Disaster Risk Financing Insurance (Surminski, Bouwer and Linnerooth-Bayer 2016). At the same time, improperly designed insurance schemes may reduce incentives to mitigate and physically adapt to the whims of nature. For example, subsidized flood insurance may increase housing construction in flood-prone areas. Details of the insurance design matter, many disincentives can be avoided. For example, index insurance for small farmers predicates the payments on easily observable indicators, like rainfall shortage, which are independent of farmer's effort. ARC, PCRAFI and CCRIF have similar arrangement at a country level (Miller and Swann 2016). R4 Rural Resilience Initiative subsidizes the climate risk insurance for the poorest farmers in exchange of their work on climate-resilience projects in local communities (Oxfam 2017).

Structural transformation requires going beyond macroeconomic stability and buffers. If climate change makes traditional economic activity unviable then government policies should aim to facilitate discovery and expansion of new more suitable activities. It is essential to engage in structural reform when the macroeconomic context is appropriate. Prudent but not excessive regulation of product markets can allow easy entry and exit of businesses, which can facilitate competition and entrepreneurship. Financial inclusion and financial markets development help potential entrepreneurs finance their initial ideas. General support of entrepreneurship - like business training, business incubators, financial and logistical support – facilitate the discovery of new activities and their transformation into viable industries.

One of the most important areas to focus on is the labor market. To help affected workers to find new activity and sources of income, governments should engage active labor market policies (ALMPs), which include job training, assistance with the job search, well-targeted job and wage subsidies, public works programs, and mental health support (ILO 2017). In areas,

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[47] Consider keeping a fund of 10 percent of GDP to cover for once-in-twenty-years natural disaster versus paying half percent of GDP each year for twenty years.

where climate change impact is highly localized, governments should apply a more comprehensive strategy combining the ALMPs with broader policy measures like clearly communicated phase-out plans; public investment and incentives for diversification and appearance of new industries; policies to increase social and physical mobility, such as investment in research, education, and transport infrastructure; early retirement schemes.[48] The strategy can be designed so that the structural transformation or transition contribute to the environmental sustainability. For example, the Philippines' Green Jobs Act subsidizes hiring and training of workers for jobs that help preserve environment (ILO 2017, Stern, Unsworth, et al. 2020). Retraining coal workers to work in the solar energy industry is a feasible and efficient instrument for the just transition (Louie and Pearce 2016) – especially if combined with the renewable energy investment into former coal-mining regions, as has been done for example in North Macedonia (Bellini 2019).

B. Reduce Exposure and Vulnerability

The first step to reduce the damage of climatic shocks is providing information. Well-designed early warning systems (EWSs) alert public about upcoming natural disaster – whether hurricane, flood, or draught - and give time to prepare, evacuate, or plan a relief. Predicting disasters well in advance and with fair accuracy is extremely hard. The work to improve EWSs continues, including the use of machine learning, big data and remote sensing, as for example at Famine EWS Network (FEWS NET) (Voosen 2020). Early warning about a natural disaster should come with clearly communicated and executed evacuation plan (or list of recommended actions), with special attention paid to the poor, who often lack awareness about the upcoming events, do not have means to transport themselves out of a danger zone, or sustain themselves while the disaster unfolds. During hurricane Katrina in the U.S. in 2005 about 25 percent of New Orleans residents – disproportionately poor – did not evacuate despite the early warning well in advance, citing lack of shelter, lack of transportation, poor health, and unclear government communication as the main reasons (Eisenman, et al. 2007). Going beyond the immediate danger of a natural disaster, public information about the current and expected climatic risks can be a key factor shaping construction and residency decisions, thus reducing the aggregate exposure to these risks.

Governments should also encourage or mandate private investment in resilience. Like with mitigation, the policy options include building codes and other regulations, as well as tax deductions – or charges if the investment does not take place - subsidies, subsidized lending, and (partial) loan guarantees among others. For example, property owners in Washington D.C. are charged a fee that is proportional to the impervious area of the property and hence reflects its contributions to the storm water runoff directly into the Potomac river, and to the potential flooding (DC Water 2020). Singapore subsidizes up to 50 percent of installation costs of rooftop and vertical greenery to mitigate the urban heat effect in addition to other benefits (Singapore Government 2020). Special attention should be paid to the poor, who often lack financial resources to invest or comply with regulations. For example, Thailand's Baan Mankong program provides infrastructure subsidies and subsidized housing loans for the urban poor if they decide to upgrade their communities (Norford and Virsilas 2016). Many other developing countries

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[48] See Oei, Brauers and Herpich (2020) for an example of structural transformation in former German coal-mining regions Ruhr and Saarland.

have similar programs. World Bank's Global Program for Resilient Housing consults the governments on resilient housing and employs drones, cameras, and machine learning techniques to automatically identify the highest risk areas where the policy intervention would be most needed (World Bank 2019a).

An important complement of the private investment is the investment in resilient public infrastructure. Examples of "grey", human-engineered infrastructure include seawalls and levees in low-lying coastal areas, drainage and water reservoirs in flood-prone areas, hurricane-proofing of power lines, or irrigation systems where regular rainfall is in short supply. Importantly, investing in nature or "green" infrastructure in many cases can be the most efficient way to build resilience, along with providing co-benefits like climate change mitigation, local economy support, and better health (Browder, et al. 2019, IUCN 2020). For example, wetland, and oyster reef restoration is the most cost effective way to reduce coastal flooding damage across the U.S. Gulf of Mexico coast (Reguero, et al. 2018), as in many other locations, and without coral reef annual damage from coastal flooding around the world would double (Beck, et al. 2018). Many cities, including New York, get their water from protected wilderness watersheds. A prerequisite for the "green" infrastructure to work is sustainable use of natural resources - water, forests, coastline ecosystems, soils, etc. Also important is to strengthen the resilience of the transport system (e.g., to floods), notably for roads that are essential for food security, and making supply chains more resilient to disruption through sourcing decisions and inventory management.

Just as with mitigation, investment in resilient public infrastructure requires effective public financial management. [49] Many countries are developing nationwide climate change strategies and incorporate adaptation into medium-term budget frameworks (Farid, et al. 2016). The UN's Sendai Framework for Disaster Risk Reduction provides a roadmap for national strategies (UN 2015). A plan how to finance the current and future adaptation spending is crucial. In developing countries, for example, the financing needs for the nationally-determined adaptation goals up to 2030 are likely six to thirteen times larger than the current level of international adaptation finance (UNEP 2016).

When adaptation to local changing conditions is not feasible, the option of last resort is migration or resettlement. Papua New Guinea, China, and Vietnam have already relocated communities due to their increased vulnerability to flooding (López-Carr and Marter-Kenyon 2015). Climate-induced migration in Sub-Saharan Africa, South Asia and Latin America is expected to rise by over 140 million people by 2050 – around 2.8 percent of the population of these regions (Kumari Rigaud, et al. 2018). Both legal and economic institutions must be strengthened to handle these increased, and often rapid and unpredictable migration flows. For

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[49] Some general principles for resilient infrastructure are to address deficient management and governance of infrastructure systems, identify critical infrastructure assets and systems so as to provide them with resources, include resilience into regulations and incentives; and use financial incentives to account for the social cost of infrastructure disruptions (Hallegatte, Rentschler and Rozenberg 2019).

example, the Platform on Disaster Displacement works to promote these institutions at country and international levels.[50]

Sea level rise may lead to the unprecedented disappearance of some sovereign states – Small Island Developing States (SIDS) – for reasons unrelated to wars, with potentially significant geopolitical and financial consequences. The enormous adaptation needs of such countries, and possibly the need, ultimately, to relocate their populations, will pose a collective action problem, since such measures are unlikely to be financed by the private sector.

It is important to understand that on a planetary scale the option to relocate is not feasible. We need to mitigate climate change if we are to avoid global catastrophic scenarios.

VI. Beyond GDP Growth: New Metrics and Policy Framework for Sustainability

The success of the low-carbon transition crucially depends on how we measure our well-being and its sustainability over time. Policies that seek to maximize GDP growth – the traditional and widely-reported indicator of economic performance - have a tendency to be biased against mitigation of environmental issues and to prioritize income over lives, towards dealing with the aftermath of natural disasters rather than preventing them, and towards investing in physical infrastructure rather than using natural resources sustainably. There is a clear need to go beyond GDP to guide policies (Stiglitz, Sen and Fitoussi 2009, Stern and Stiglitz 2021).[51]

The key priority is to keep track of our wealth, and natural capital in particular.[52] The System of National Accounts must transition from a flow-centered focus on GDP to a stock-centered focus on a broad definition of capital. The United Nations Environment Programme's Inclusive Wealth Index (IWI) is a step forward along these lines (Managi and Kumar 2018, Dasgupta, et al. 2015, Asheim and Weitzman 2001). A similar approach is used in the World Bank's Changing Wealth of Nations project (Lange, Wodon and Carey 2018), while the UN's System of Environmental-Economic Accounting delineates the main principles behind measuring natural capital/ecosystems in physical and monetary terms (Hein, et al. 2020). The Global Footprint Network's National Footprint and Biocapacity Accounts measure sustainability not in monetary units but in units of biologically productive area it takes to provide for humanity's aggregate demand without reducing Earth's productive capacity (Lin, et al. 2018).

While the wealth indexes above keep improving their methodology, significant challenges remain. It is hard to reliably assess stocks of natural assets like wildlife, biodiversity, freshwater, soil, and especially to account for all ecosystem services they provide and their quality.[53] It is

[50] https://disasterdisplacement.org/

[51] Nicholas Stern was a member of the Commission on the Measurement of Economic Performance and Social Progress (Stiglitz, Sen and Fitoussi 2009).

[52] Natural capital is defined as the stock of natural ecosystems on Earth including air, land, soil, biodiversity and geological resources, which underpin our economy and society by producing value for people, both directly and indirectly. The stock of natural ecosystems provides a flow of services (ecosystem services).

[53] As a result, these assets are not being accounted for, e.g. their value is assumed zero.

even harder to estimate prices at which natural assets should be valued. Many natural assets are not traded on markets, and even when they are, market prices often do not fully reflect these assets' true social value because of externalities—some of which have yet to be discovered by science. For example, the average value of a great whale is estimated to be over two million US dollars, mainly due to its recently discovered role in fertilizing phytoplankton. This is orders of magnitude more than the market price of whale meat in places where it is still being traded (Chami, et al. 2019).[54]

Dependence between prices and available stocks of natural assets can also be highly non-linear. The usefulness of many ecosystem services is not adequately perceived until their deterioration is advanced. If freshwater is abundant it can be quite cheap, but it is priceless in times of draught. If the change in stock of GHGs in the atmosphere is small, so that the global temperature increase stays below 2°C, the social cost of carbon can be moderate, but it can jump up disproportionately if we go above 2°C and let some of the catastrophic risks materialize. These non-linearities reflect the fact that some natural assets—critical natural capital like air, water, stable climate, biodiversity, etc.—when highly stressed, cannot be easily substituted by other types of capital to ensure that well-being can be maintained, let alone increased over time. It is therefore important to understand that price non-linearities and uncertainty may lead to an underestimation of the role of natural capital, and paint a rosy picture of sustainability if expressed by single wealth indexes.

Despite these difficulties, the wealth indexes are an important step in the right direction, and should benefit further from continued research into the natural capital accounting (Turner, Badure and Ferrini 2019).

In addition, the wealth indexes can be complemented by a dashboard approach, e.g. reporting a broad set of human, social and environmental indicators along with GDP (Laurent 2019). An advantage of the dashboard approach is that it allows for different dimensions of well-being to be complementary and cumulative, and it does not require assessing prices/weights at which the dimensions are to be summed up in a single index.

Whether dashboard or unidimensional indices, the measures of welfare and sustainability need to be used in research and policymaking. Governments should employ them for ex-ante and ex-post policy evaluation, like Bhutan already does (OECD 2016). Researchers working on IAMs should also go beyond economic activity when analyzing optimal mitigation paths. Same applies to international financial institutions, including the IMF and the World Bank, which should base their policy advice not only on conventional macroeconomic and financial indicators, but also on a dashboard of welfare and sustainability indicators.

Even more importantly, if societies are to take seriously the existential threat posed by climate change, the conceptual framework used by policymakers must treat planetary boundaries—notably climate overshoot—as a hard constraint. This can be done by

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[54] Similarly, elephants are key to keep soil fertile in Africa (Stokstad 2020), and tapirs are essential to forest restoration in Amazon (Paolucci, et al. 2019).

establishing annual carbon budgets at the national level that are binding on all aspects of policy, including budget laws (High Council on Climate 2019).

VII. Dealing with Climate Change: How to Make the Transition Inclusive?

The transition to low-carbon economy is our only option, but it is a major undertaking. It involves the rise of new sectors and industries, but also the retirement of some old ones. It creates new jobs and offers new opportunities, but it requires altering our consumption habits and learning new skills. If the transition is inequitable or socially unjust, it will ultimately fail. But if done right, it will unlock new sources of development – a growth story for the 21st century, which would not only be sustainable, but also inclusive. Distributional issues are thus critical to addressing climate change.

Many policies discussed in this paper bring about important inclusion co-benefits by design:

- Climate change and other environmental issues disproportionately affect the poor, especially those living in developing countries. Climate change mitigation would therefore be particularly beneficial for the poor.

- Poor subsistence farmers are often *de facto* owners and primary users of natural assets that are key to the mitigation and adaptation: forests, wetlands, agricultural land, coastal waters. Prompting sustainable use of these assets - investing in land restoration and sustainable agriculture, creating financial instruments to reflect the true social value of these assets, and paying for the provided ecosystem services – would not only help our planet but also provide sustainable livelihood for the owners. These policies would also help empower women as they make more than 40 percent of agriculture labor force around the world[55] and they are often responsible for the food production and collection of fuel and water in the poorest households (Doss 2011).

- Investment in sustainable urban infrastructure – water and sanitation, green areas, slum upgrading, public transport – is another example of a policy with widely shared benefits.

Mitigation and adaptation policies also create job and training opportunities, including for the youth, low-skilled, and long-term unemployed. Ethiopia's National Forest Sector Development Program aims to reforest 15 percent of the country, contribute 50 percent to the national emission reduction target by 2030, and at the same time create over six hundred thousand jobs – over a quarter of the country's unemployed (MEFCC 2018). Carbon taxes can reduce economic activity in the short run, but their effects on net creation of jobs are much less clear, as the renewable energy industry is more labor-intensive than coal. In the U.S. solar and wind already employ almost three times as many people as coal despite a smaller share in total energy production (Heutel 2018). Unlike fossil fuel deposits, potential for solar and wind energy production is widely distributed across the globe and within countries (Deng, et al. 2015). This creates opportunities to reduce disparities by investing and creating jobs in laggard regions,

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[55] This is larger than the female share in total labor force.

provide electricity supply even where the grids are down or non-existent, together with an additional co-benefit of energy self-sufficiency and security for more countries.

For some policies, inclusion must be deliberate:

- The effect of a carbon tax on the poor's purchasing power should be alleviated by well-targeted social transfers or other pro-poor public spending programs.
- The "stranded" workers and regions need to be helped via job training, help with reallocation, and regional investment programs.
- Regulations to promote energy efficiency or build up resilience should come with financial incentives or government programs for the poor to enable them to comply.
- Natural disaster evacuation plans should be designed in a way that even the most vulnerable have information and means to escape and weather the disaster.
- Natural habitat and wildlife conservation as well as transition to sustainable use of resources should be accompanied by mitigating measures for the poor.

Success of the transition also depends on other more general policies and factors. It is key to maintain an inclusive decision-making process: extensive communication about the reform and consultations with all stakeholders. This includes participation of women at all levels of climate action, as climate change is not gender-neutral (GGCA&UNDP 2013). Going beyond GDP in measuring well-being and sustainability helps focus policy measures on the right priorities. Macroeconomic stability and secure property rights are necessary conditions for massive investment to take place. Effective decentralization frameworks are needed to spur investment by local governments. Structural reform and social safety nets, investment in health, education, and infrastructure, promotion of gender equality are key to smooth structural transformation, abate policy effects for the poor and the most affected, and advance inclusive growth agenda in general. And at the basis of it all are inclusive political institutions and effective governance and anti-corruption frameworks.

The timing of reforms also matters. The costs generated by increased carbon taxation would be reduced if such increases are introduced at times of low commodity prices when electricity and fuel for vehicles are relatively cheap. Changes in taxation in general as well as the structural reform are better implemented during economic booms, when the cost of adjustment to the new rules is attenuated by faster economic growth. Using the revenues from carbon taxes to compensate losers is critical. Recessions, by contrast, are the most appropriate time to expand financial incentives and boost investment in sustainable infrastructure – helping to both tackle climate change and expand the economy when it is most needed, while contributing little to inflation. The severe downturn caused by the COVID-19 pandemics is a prime example of a time when green recovery policies should be employed (Stern, et al. 2020, Bhattacharya 2020, Bhattacharya and Stern 2020).

A. Making the Post-COVID-19 Economy Sustainable

The COVID-19 pandemic is a profound crisis that differs in fundamental ways from previous crises, as it combines health, economic and financial aspects and has resulted in extraordinary policy action. To a significant extent, it is endogenous, as it is rooted in unsustainable modes of production and consumption. The pandemic likely originated in a pathogen that passed from wild animals to humans in the context of ecosystem degradation (IPBES 2020, WHO 2021). The climate change challenge is similar to the pandemic in some ways: both revolve around questions of system resilience, political economy, and international cooperation. It is also different, because the geological changes triggered by carbon-intensive growth pose an existential threat to civilization, and will last for millennia, if not millions of years.

In addition to climate change, the 20th century saw unprecedented ecological change and degradation of ecosystems and biodiversity, together with dramatic increases in human and domestic animal populations. This has led to unprecedented contact between humans and animals, providing ample opportunities for pathogens to transfer between species and generating a worldwide increase in emerging zoonotic diseases and outbreaks of epidemic zoonoses (IPBES 2020). Pandemic risks have been exacerbated by globalization, a key channel being air traffic, which doubled between 2006 and 2018 to over 4.3 billion passengers, thus generating the largest vector in history for the spread of emerging diseases.

Given the link between unsustainable economic activity and pandemics, COVID-19 is unlikely to be a one-off. It is likely just the first instance of a century of shocks related to environmental degradation. In words of (Tooze 2020), we are living through the "first economic crisis of the Anthropocene." Worryingly, unsustainable growth is being exacerbated by the crisis, with accelerating deforestation and wildlife poaching, reversals of environmental regulations, and the implementation of carbon-intensive economic recovery policies. All of this strongly underlines the importance of making the global economy sustainable and resilient.

Precisely, the COVID-19 crisis could prove to be a watershed moment in our collective ability to tackle climate change and ecological degradation. In 2020, GHG emissions are projected to have fallen by a record amount. The challenge is immense, as this decline needs to be maintained for three decades to achieve carbon neutrality by 2050. Instead, emissions have rebounded following the gradual reopening and recovery of economies. The broader context is encouraging, however, with public support for ambitious climate action having grown substantially in developed countries in the context of the COVID-19 crisis. Equally important, the crisis has shown governments' ability to intervene rapidly on a large scale, driving a decisive increase in the role of the state (Helm 2020).

The stakes of the transition to a sustainable global economy are clearly immense. To enable this "Great Transformation" in the required timeframe, governments must ensure that recovery plans are compatible with climate stability and national carbon budgets. Rapidly-implementable, labor-intensive public investment with high economic multipliers and large climate co-benefits are essential to underpin a sustainable recovery and avoid locking in emissions (Stern, et al. 2020, Bhattacharya 2020). Specifically, a survey of policymakers suggests that five policies should be prioritized: clean physical infrastructure, building efficiency retrofits, investment in education and training, natural capital investment, and clean R&D (Hepburn, et al. 2020). In lower- and middle-income countries, the focus should be on rural support spending.

VIII. Conclusion

Business as usual cannot continue. A decade of current GHG emissions remains before global mean temperatures surpass 1.5°C and risk triggering catastrophic irreversible changes to the planet's ecosystems, thus putting our livelihoods in jeopardy and driving millions into extreme poverty. A just transition to a net-zero emissions, climate-resilient world economy is the only viable way forward. The transition represents not a cost or a burden but the greatest economic, business and commercial opportunities in modern times (Stern 2021). If it is achieved, not only will climate stability be safeguarded, but our societies will be more prosperous, healthier, and more inclusive over the long term. This paper outlines the key policies and policy framework changes that are required for a successful transition: putting a price on carbon, promoting sustainable use of natural resources, aligning the financial system with climate objectives, boosting public spending on sustainable infrastructure and innovation, deploying low-carbon industrial and innovation policy, systematically integrating climate change into public financial management, building resilience and adapting to the climatic changes that are coming, better measurement of well-being and sustainability, and crucially, making the transition fair by ensuring socially just outcomes. The world must act now to seize the growth opportunity of the 21st century. In the words of "A Letter to the Future," carved in memory of Okjökull – the first extinct glacier in Iceland: "This monument is to acknowledge that we know what is happening and what needs to be done. Only you know if we did it."

IX. Appendix I. Assessing Socioeconomic Damages from Climate Change

An important limitation of *microeconomic* estimates of climate damages relates to their methodology: using annual (i.e., high-frequency) temperature changes to determine the effects of climate change, which corresponds to decadal (i.e., low-frequency) temperature variations. Little is known about how responses to high-frequency temperature changes differ from responses to low-frequency temperature changes—that is, to climate change. On the one hand, one could expect high-frequency temperature changes to have smaller effects than lower-frequency changes, as some effects (deforestation or desertification, for example) are cumulative. On the other hand, one could expect the opposite: high-frequency changes could have larger effects than low-frequency ones because there is more time to adapt to low-frequency temperature variations than to high-frequency temperature ones. Microeconomic studies thus tell us very little about long-term climate change. Indeed, large output losses from climate change several decades in the future are likely to occur through channels other than short-term temperature variations. Such channels include the collapse of ecosystems, migrations, conflicts, migrations, and so forth. Taken together, these limitations highlight the need for caution when interpreting the results of microeconomic studies.

The main *macroeconomic* approach to evaluating climate damages is based on the use of Integrated Assessment Models (IAMs). There are two main kinds of IAMs: cost-benefit IAMs and process-driven IAMs. The latter focus on drivers and processes of change in global energy and land use systems linked to the economy. These models do not focus on damages caused by climate change but on pathways to achieve, in a cost-effectiveness framework, a desired level of climate stabilization, such as 2°C. Process-based IAMs are used to quantify shared socioeconomic pathways (SSPs) currently being developed by the IPCC (IPCC 2018). An important initiative is the Integrated Assessment Model Consortium (IAMC), which uses these types of IAMs to develop mitigation policies.

Unlike process-driven IAMs, cost-benefit IAMs seek to assess climate damages. Their starting point is the integration of climate issues into the neoclassical growth model (Solow 1956). The Dynamic Integrated Climate-Economy (DICE) model, developed by (Nordhaus 2014), has become the benchmark model for this type of IAM. IAMs that follow the DICE approach are commonly used by academic economists to estimate the social cost of carbon. Despite their prominence and the perception that they represent the overall consensus, these types of IAMs suffer from two major limitations: they significantly underestimate the risks of climate change, and they grossly overestimate the cost of deep decarbonization (Stern and Stiglitz 2021). We briefly review these shortcomings below.

The first major limitation is the underestimation of climate risks: most IAMs embody extreme positive cases of climate outcomes (Stern 2015, Stern 2016).[56] The impact models on which they are based generally fail to account for the scale of the risks associated with global warming of 3-4°C or more. Further assumptions built into the economic modeling of growth, damages and risks come close to assuming directly that the impacts of climate change will be modest and to excluding the possibility of catastrophic outcomes.[57] This is problematic, as at its core, the main concern about climate change is the catastrophic damages that could result from average temperature increases at or above 3°C, 4°C or 5°C, yet IAMs commonly developed by academic economists directly assume away such outcomes. For example, in most of these IAMs, the climate damage curve is assumed to be quadratic, and large increases in temperature (e.g., 5-6°C) are estimated to reduce output by only a few percentage points, thus clearly contradicting the science. In addition, the population is determined exogenously, such that IAMs typically cannot analyze major impacts of high temperatures, such as migration of climate refugees, conflict, and large-scale loss of life.

The second major limitation of IAMs is that they generally fail to account for the dynamic benefits of innovation, learning and feedback loops that promote institutional and behavioral change, discovery and economies of scale (Stern 2018). The dominant approach to IAMs ignores innovation and inertia, which can have a large impact on the cost of abating GHG emissions, as the latter depends on previous efforts and may be largely transitional (Stern 2016).

Even more importantly, as noted by (Stern 2016)**, these types of IAMs tend to assume a first-best economic setting (in which the only externality is the greenhouse gas externality), rather than a realistic second-best setting, in which multiple externalities coexist and interact.** For example, credit market failure and knowledge spillovers play a major role in constraining investment in renewable energies. By construction, therefore, such models typically ignore the role of finance in macroeconomic dynamics and climate policy.

As a result of these limitations, while cost-benefit IAMs can help provide useful qualitative indications on how complex systems behave, their quantitative insights cannot be used for policy guidance (Stern and Stiglitz 2021). The upshot is that policy should be based on aversion to risk and the avoidance of disastrous outcomes. Put differently, instead of striving for an "optimal" degree of global warming, as cost-benefit IAMs do, policy needs to be based on a precautionary principle that seeks to minimize the risk of catastrophic climate outcomes.

X. Appendix II. The Challenge of Climate Change

Environmental issues pose an incredibly difficult challenge to human societies. To focus only on climate change, GHGs impose an externality: they are associated with activities that have a direct impact on third parties (including both current and future generations) that do not participate in the production of the emitted GHGs. Without appropriate policies, GHG emissions inflict damages on others, yet emitters do not bear the costs of the damages that result from their emissions. This represents a market failure, since markets fail to generate prices that accurately signal how to allocate resources to their most productive use, and prices fail to reflect the true cost to society of economic activities.

The GHG externality is unique: it is global in scope and impacts; it involves significant uncertainty and risk in the scientific chain of causation; it is long-term; it is governed by a stock-flow process and thus it is difficult to react quickly if mistakes are made; and, as we have seen, the effects are potentially huge and irreversible. For these reasons, the Stern Review described climate change as "the greatest market failure the world has ever seen." Naturally, dealing with such a uniquely multifaceted externality is extremely difficult (Stern 2007).

There are three other ways of thinking about climate change. They are complementary and underline the magnitude of the challenge posed to modern societies.

The first school of thought argues that, beyond a critical climate threshold, defining climate change as an externality reverses the basic logic of the problem: since economic activity itself depends on natural systems, by jeopardizing natural systems climate change ceases to fit the definition of an externality and instead is better described as a threat to human security (Grubb, Hourcade and Neuhoff 2014).

The second conceptual approach to the economics of environmental issues was developed by (Kapp 1950)**.** Kapp argued that, inherently, profit-based market economies involve attempts by firms to reduce costs whenever and wherever possible, thus ignoring costs that can be shifted to third parties or society at large. This phenomenon inevitably generates environmental degradation. While public policies can seek to correct these externalities, Kapp saw two problems. First, it takes time for policies to be effective—potentially a long time—given the need to correctly identify an externality and design and implement an appropriate response, in a context where powerful vested interests may effectively resist new regulations. This can enable environmental degradations to run their course. Second, even when policies manage to correct externalities, they always lag behind new environmental externalities that are being discovered and exploited by firms' profit-driven cost shifting. Put differently, Kapp's core argument was that environmental degradations are better defined as cost-shifting successes, rather than market failures.

According to this reasoning, with policies and regulations continually running after new externalities, the odds are that society will end up facing an externality that cannot be corrected in time, and one or more planetary boundaries will be crossed. Implicit in this theory of social costs is the idea that there are limits to markets' ability to solve environmental problems, even assuming that policymakers are able to identify and address externalities as they are discovered. This suggests that successfully tackling environmental disruptions requires greater reliance on strategic planning by the state, whose motives are, in principle, not based on profit maximization.

Finally, the concept of Common Pool Resources (CPRs), developed by Elinor Ostrom and defined as "systems that generate finite quantities of resource units so that one person's use subtracts from the quantity of resource units available to others" can be applied to the climate (Ostrom 1990) (Ostrom 2010). The remaining global carbon budget for warming to stay under 1.5°C or 2°C can be seen as a CPR, since emissions in one country deplete the carbon budget available to other countries.

Regardless of how one thinks about the economics of climate change, an additional challenge is that our knowledge about the interaction of the economy and natural systems is far from complete. Climate change is likely to uncover previously hidden interdependencies, revealing new and potentially enormous social costs. An example is the huge locust swarms that devastated crops in East Africa and Central Asia in 2020, causing food crises that threatened the lives and livelihoods of tens of millions of people. These locust plagues partly resulted from an increased number of cyclones in the Indian Ocean, itself a consequence of climate change. Ocean acidification is now considered one of the key threats to marine ecosystems, in particular coral reefs, and livelihoods that depend on them, but the issue was brought to attention of scientists and policymakers only in early 2000s (Ocean Portal Team 2020). Another prominent example is the COVID-19 pandemic, which likely originated in pathogens passing between species in the context of ecosystem degradation, with climate change and biodiversity loss being major drivers of increasing environmental degradation.

Overall, the interdependency between economy, climate change and environmental degradations can be seen as a complex system of interaction among different risks. This system is characterized by three aspects: irreversibility—environmental degradations can persist long after the goal of decarbonization has been achieved; non-linearity—many Earth subsystems can bifurcate in an abrupt way; chaotic dynamics—crossing planetary thresholds may generate a cascade of tipping points that would result in an unhabitable Earth (Lenton, et al. 2019). What makes the potential social costs of climate change particularly difficult to assess is what one could call "unknowable unknowns": the full range and characteristics of interdependencies between natural and human systems.

The upshot is that regulatory systems and discretionary policies may not be able to address certain negative externalities in time, thus generating enormous social costs or contributing to the crossing of irreversible tipping points in the Earth system. These threats warrant the adoption of the precautionary principle in the design of policies and policy frameworks.

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