POLICY PAPER NO. 1

Climate Change and Economic Growth: What Lies Ahead

Shahid Yusuf

GROWTH DIALOGUE INSTITUTE

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Abstract

Mean global temperatures have risen by 1.2°C over the preindustrial average and already there is mounting evidence that the environmental impact is accelerating. Severe weather events have become more frequent, with increasingly destructive wildfires, prolonged droughts, thinning Arctic ice, vanishing glaciers, bleaching coral reefs, shrinking biodiversity, and acidifying oceans. The urgent need to achieve carbon neutral development and to prevent the mean temperature from rising above 1.5°C, is more apparent than ever. Scientists warn that the global ecosystem might be perilously close to tipping points that could lead to large and irreversible climatic change and cause major economic impacts.

Although IPCC reports and the vast literature on the pace and magnitude of climate change make a compelling case for swift action on several fronts, efforts to control greenhouse gas (GHG) emissions, to mitigate warming and to adapt to ongoing and impending changes in the environment, have made limited headway. National and corporate decisionmakers are deterred: by near term costs and budgetary stingencies; by fears that actions taken to contain climate change would constrain GDP growth and undermine industrial competitiveness; by the realization that fossil fuel resources and much industrial capital would become stranded assets; by the hope that current climatic trends might flatten and future advances in technology could make it easier and cheaper to cope with climate change; and by the unwillingness to risk arousing the ire of the public or of the business community by taking steps that inflict short term financial pain even though the longer term collective benefits might be large.

Fortunately for the planet, public awareness of the existential threat posed by climate change has risen and has begun to sway the thinking of politicians and captains of industry and finance. After years of foot-dragging and discord within and between developed and developing nations, it appears that binding, monitorable and enforceable commitments by all the key national participants might be in the offing. With the window of opportunity to cap the increase in global mean temperature at 1.5°C narrowing rapidly, it is imperative that Emerging Market and Developing Economies (EMDEs) in particular see their way clear to undertaking climate-responsible investments. Doing so will also require climate compatible economic growth strategies. Our hope is that this paper can help provide decisionmakers with the essentials on each of these issues and induce commitments to far-reaching actions that are both in the national and global common interest.

The paper briefly summarizes where climate change is heading, reviews the status of international attempts to limit GHG emissions, and identifies roadblocks to an enduring agreement. Second, the paper examines the economic implications of rising temperatures for EMDEs, and takes a critical look at some of the technological fixes that are surfacing. Third, the paper identifies measures developing countries could pursue in conjunction with others so as to take control of the climate change agenda. It is only by anticipating and planning for the challenges to come that countries will be able to contain the costs and sustain needed rates of growth, while achieving carbon neutrality in a reasonable period of time.

One key takeaway is that climate change must be central to all projections and inform virtually every facet of developmental decision-making because even a more favorable global outlook will entail major dislocations for many countries. At the same time, the effects of climate change will create new challenges for those concerned with poverty reduction, labor productivity, the incidence of inequality in its several manifestations, migration pressures, and societal stability. Going forward with status quo policies will be very damaging for all concerned.

Climate Change and Economic Growth: What Lies Ahead

Shahid Yusuf

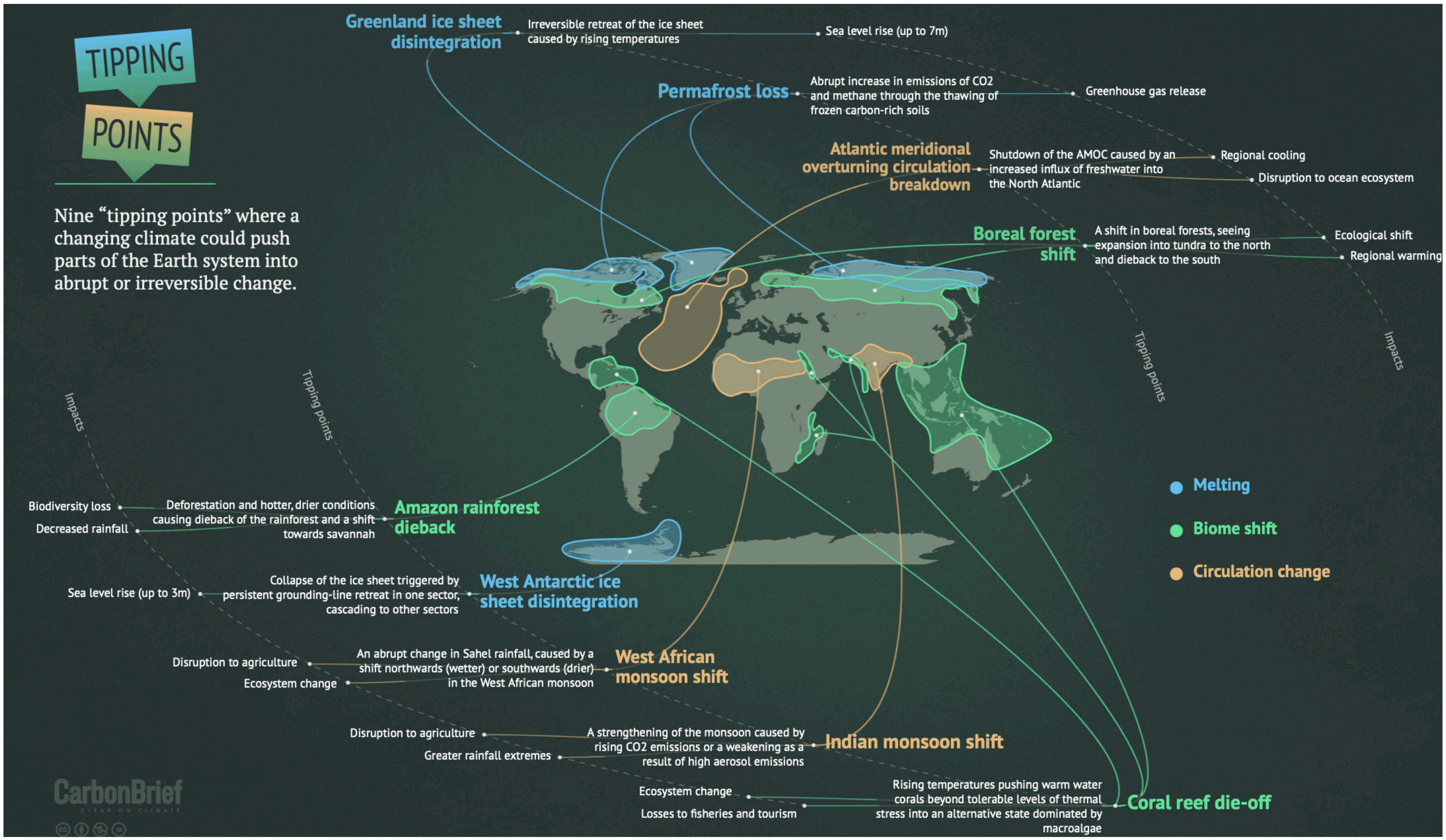
Climate Change Has Made Development More Challenging

Climate change is gathering momentum and the global ecosystem may be steering towards a cascade of exceedingly worrisome tipping points (Figure 1).[1] Some tipping points, such as monsoon shifts affecting West Africa and the Indian subcontinent, would cause immense regional hardship. Others, such as the release of permafrost methane hydrates and the disintegration of the West Antarctic ice sheet,[2] or the melting of the Greenland glaciers, would be catastrophic on a global scale. The magnitude of the risks is becoming ever more apparent, supported by the rapidly accumulating multidisciplinary research. International agencies are sounding the alarm, public awareness is on the rise, the corporate sector is beginning to stir, policymakers in some leading countries are expressing a willingness to grasp the nettle, and the opposition from climate change deniers appears to be weakening.

All this is encouraging, but valuable time has been lost while the science was debated, countries squabbled over the apportioning of blame, and high-income countries parried demands from developing nations for compensatory financing to offset the cost of measures that would reduce energy intensity and greenhouse gas (GHG) emissions. A good chunk of the carbon budget left to exploit before mean temperatures begin exceeding 1.5°C has already been utilized. And at current trend rates of carbon emissions, the balance could be exhausted by 2030 if not earlier.[3]

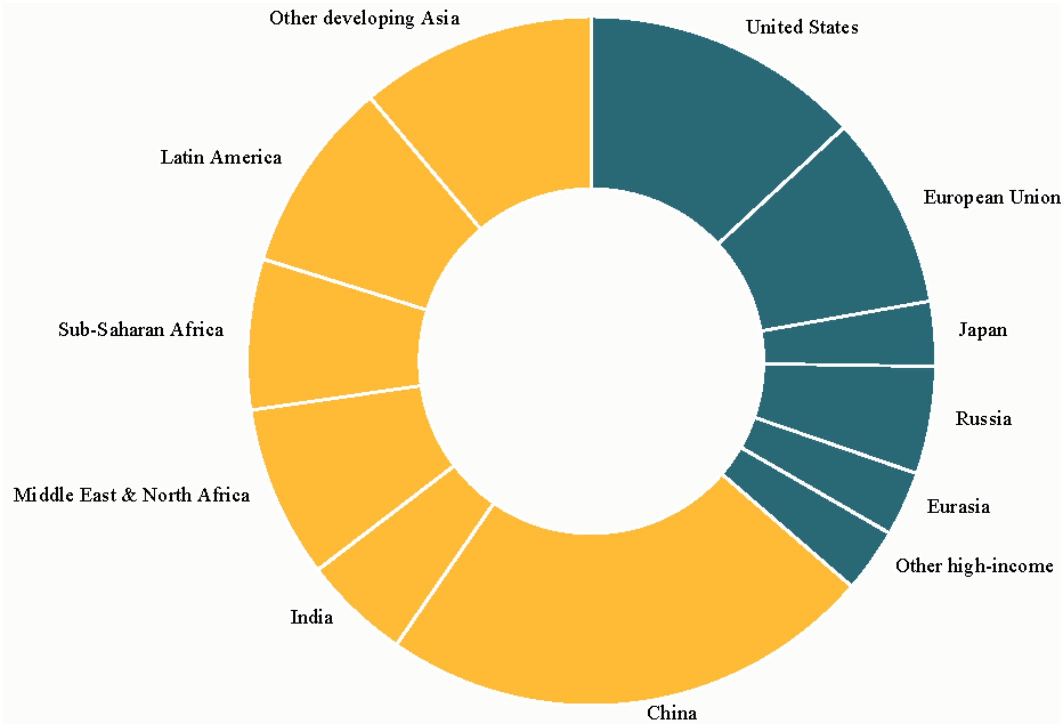
Developing countries must be a part of globally coordinated strategy to check climate change while there is a (narrowing) window of opportunity.[4] Currently they account for close to a third of total emissions; but as they become more populous, urbanize, motorize, industrialize, and their per capita incomes rise, the upward trend of their emissions will steepen (Figure 2).[5] Moreover, developing countries will bear the brunt of the climate change and its economic consequences, while also being least able to afford the damage. A strong case can be made for advance planning, a well-articulated strategy and systematic implementation of measures to green the growth of developing countries. Early movers can safeguard and possibly improve their growth prospects, while simultaneously slowing the concentration of GHGs in the earth's atmosphere.

Figure 1: Climate change tipping points



Source: McSweeney (2020).

Figure 2: Carbon emissions by country and region



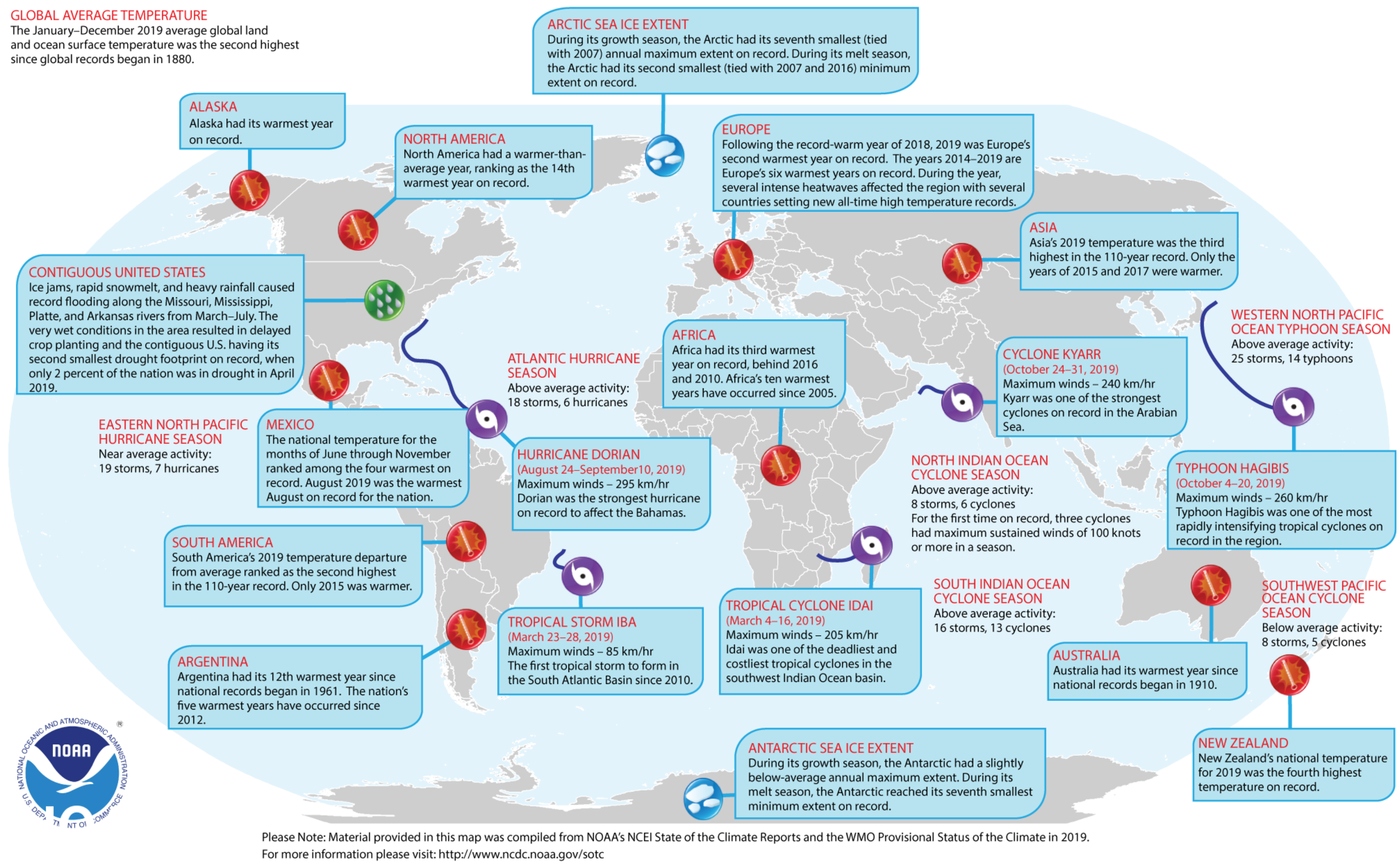
Source: CGD (2015).

The purpose of this paper is threefold. First, it briefly summarizes where climate change is heading, reviews the status of international attempts to limit GHG emissions, and identifies roadblocks to an enduring agreement. Second, the paper examines the economic implications of rising temperatures for developing countries and takes a critical look at some of the technological fixes that are surfacing. Third, the paper identifies measures developing countries could pursue in conjunction with others so as to take control of the climate change agenda. It is only by anticipating and planning for the challenges to come that developing countries will be able to contain the costs and sustain needed rates of growth, while achieving carbon neutrality within four or five decades.

1. How Climate Change and Its Negotiations are Evolving

Evidence of climate change is widespread. The last five years were among the warmest on record, with 2020 the second warmest year after 2016.[6] Warming is greater over land and causing more frequent severe weather events—heat waves,[7] droughts, flooding, wildfires, and hurricanes (Figure 3).[8]

Figure 3: Selected significant climate anomalies and events in 2019

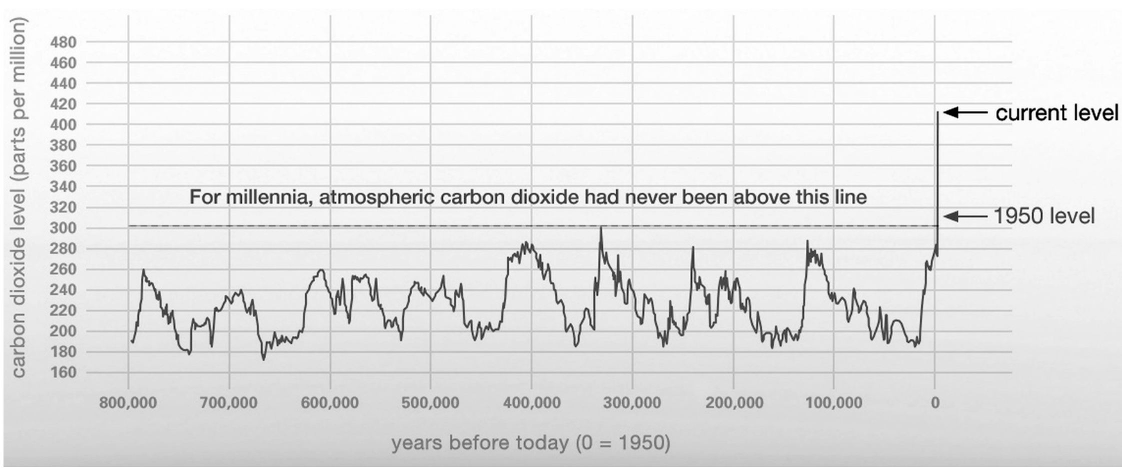


Source: ITU (2020).

The majority of climatologists are of the view that the situation is becoming dire.[9] They also warn that developing countries, especially those lying in the tropical belt, will be the hardest hit. Higher temperatures and weather extremes will impact, food security,[10] water availability,[11] mortality,[12] labor productivity,[13] learning by students,[14] migration patterns,[15] physical infrastructures,[16] and lead to an increase in the incidence of conflicts[17] and of localized violence.[18] Major cities (some in deltaic regions) such as Mumbai, Kolkata, Guangzhou, Jakarta,[19] Ho Chi Minh City, Bangkok, and Lagos are likely to be seriously imperiled absent costly protective investments.[20] We intend to examine some but clearly not all of these threats as they impact on the viability of sustainable growth in countries faced with high poverty levels and major uncertainties with respect to their economic outlooks.

Global mean surface temperatures during 2006–2015 were 0.87°C higher than the average for the period 1850–1900[21] and are rising by 0.2°C per decade as CO_2 continues to accumulate. The COVID-19 pandemic reduced economic activity, leading to a 7 percent decline in volume of carbon emissions, mainly from a slowdown in the transport sector.[22] Nevertheless, atmospheric accumulation inched upwards from 416 ppm in April 2020 to 419 (or 421 ppm) a year later[23]—a 50 percent increase over the 278 ppm recorded in preindustrial times (Figure 4).[24]

Figure 4: Increase in atmospheric CO_2



Source: ITU (2020).

At the end of the 20th century, ocean temperatures had risen by 0.33°C and sea levels were 8 inches higher than at the beginning. Marine heatwaves are becoming more frequent and high temperatures that persist for five days or more damage the growth of phytoplankton, hurt fisheries, and exacerbate the bleaching of coral reefs.[25] Over the first two decades of the 21st century, water levels have been rising at 1.3 inches per decade as the oceans absorb 90 percent of the excess heat. Oceans are also absorbing some 22 billion tons of CO_2 each day and are becoming more acidic with deleterious consequences for all aquatic organisms.[26] Arctic sea ice cover has fallen sharply as has the average thickness of the ice. Glaciers are melting in mountainous regions; there is less snow cover in the Northern Hemisphere; and snow melts earlier in springtime.[27]

According to the Germanwatch Global Climate Risk Index, South and Southeast Asian countries and a few in the Caribbean region were the countries most affected between 2000 and 2019, but they were not the only ones.[28] Reliance on agriculture and the coastal concentration of the population exacerbates countries' vulnerability to climate change. Coastal cities are more exposed to the full force of hurricanes and tidal waves and, over the longer term, to rising sea levels. Agricultural activities near the coast are also vulnerable to climate change risks, including severe weather events that lead to flooding, subsiding land, damage to infrastructure, soil erosion, and increasing salinity of soil and groundwater.[29]

Careful management of water resources will become critical for countries in Asian river basins (e.g., Mekong, Brahmaputra), to compensate for building of upriver dams, reduced flow of water because of more frequent droughts, and shrinking Tibetan glaciers.[30] Moreover, weakening summer monsoons and more frequent heavy downpours will adversely impact South Asia and Southern China, both of which have suffered from severe flooding in recent years.[31] Water-related threats to food security are already a concern for some countries, and will become even more pressing.[32]

Barring a coordinated and concerted effort by all the major emitters of GHGs (Figure 2), average temperatures will continue rising and could exceed 2°C by 2050 and approach 4°C by the end of the century.[33] Whether or not the leading GHG emitters are able to settle their differences and take steps—in conjunction with measures being taken by private businesses and subnational governments across the world—to contain warming to 2°C or less,[34] some of the damage has already been done. Higher temperatures and weather extremes[35] are here to stay[36] and developing countries must act to both contain the carbon/GHG emissions[37] and mitigate the consequences of climate change.

1.1. The International Climate Regime

Climate change has aroused concern for decades. In 1988 the United Nations Environment Programme and the World Meteorological Organization established the Intergovernmental Panel on Climate Change (IPCC) to provide periodic updates on the state of knowledge on climate change and recommendations.[38] The 1992 Earth Summit held in Rio de Janeiro was an early attempt to arrive at a consensus on how to achieve sustainable development.[39] The declarations, agendas, and commissions that materialized may have heightened awareness but did little to reduce emissions. However, they did lead to the ratification of the UN Framework Convention on Climate Change (UNFCCC) by 197 countries. This established an annual forum known as the Conference of the Parties (COP) to discuss ways of controlling the release of greenhouse gases. These meetings led to the adoption of the Kyoto Protocol in 1997 and its ratification in 2005.[40] The Protocol (from which the United States later withdrew) legally bound all signatories to cut emissions by 5 percent from average levels in the 1990s but did not compel countries to act or impose penalties on those that did not adhere to the agreed terms.[41]

In 2015, 195 countries entered into the Paris Agreement (COP 21, signed in 2016)[42] and agreed to enter pledges to reduce emissions by as much as would be required to prevent global mean temperatures from rising by more than 2°C in excess of preindustrial levels and make efforts to cap the increase to 1.5°C. The aspirational goal of the Agreement was to arrive at net zero emissions by the second half of the 21st century. Each signatory nation set its own (best effort) target and was required to assess progress every five years as part of a "global stock-take."[43] However, as with the Kyoto Protocol, there was no mechanism for enforcing compliance and no penalties for falling short of targets.

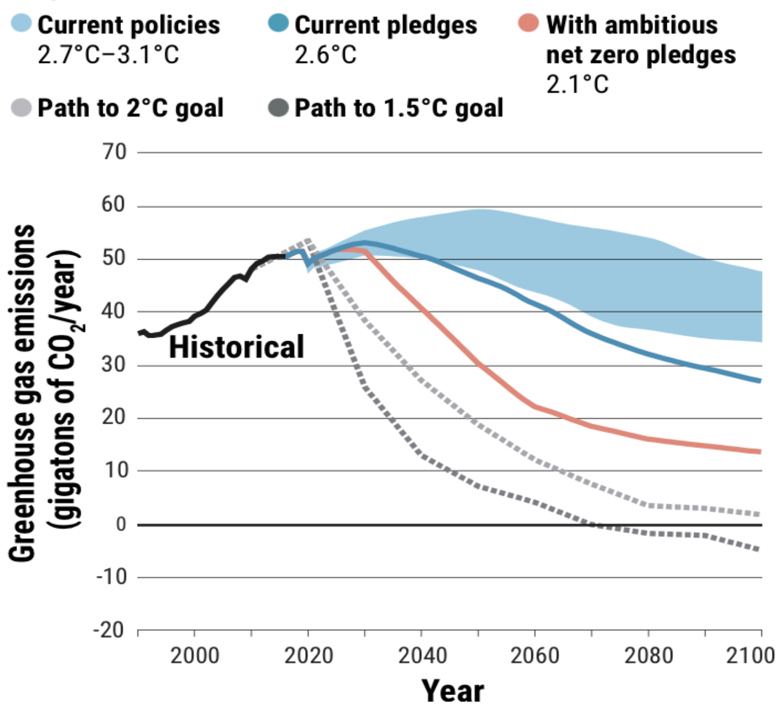
There have been a few encouraging developments in the past two years. The EU and several other high-income countries including the United Kingdom, Japan, and the Republic of Korea have renewed their pledges to cut net emissions to zero by mid-century.[44] In December 2020. China, which is the largest emitter (29.7 percent), pledged to peak its GHG emissions by 2030 and to push for net zero emissions by 2060.[45] The reaffirmation of the Paris Agreement by the United States after withdrawing two years earlier was a second promising development.[46] On April 21st, 2021, President Biden announced that the United States (the second largest emitter, 15.3 percent) would endeavor to scale back its GHG emissions by 50 percent by 2030 compared to levels reached in 2005.[47] A third development was data suggesting that the rate of warming was beginning to ease slightly because of regulatory measures taken to date, the increasing reliance on gas as a substitute for coal and on renewable sources of power, and a slowing of global GDP growth rates.[48]

These pledges hold out hope that climate change could be contained. But other developments give rise to doubts. Russia and Brazil have demonstrated little willingness to abide by the Agreement.[49] The developed nations have been slow thus far to meet their commitments to fund renewable energy and other emission-reducing measures in emerging markets and developing economies (EMDEs). Financing of research on renewables has risen very little (US$4.9 billion). Moreover, countries such as India and China have a vast amount of coal-fired generating capacity and new plants in the pipeline. Indian policymakers have expressed an intention to replace aging coal fired plants with renewables.[50] Although China has declared an intention to wean itself away from a heavy reliance on coal, over 38 GW of coal-fired power capacity was activated in 2020, and there are many new projects in the pipeline (247 GW is in the planning/development stage). Moreover, China continues exporting coal-fired generating equipment to countries participating in the Belt and Road Initiative (BRI), with investment amounting to US$43 billion.[51] In fact, these countries collectively could be releasing one half of all carbon emissions by 2050.[52]

Clearly, the Kyoto Protocol and the Paris Agreement have focused attention on climate change, spurred activism and are beginning to deliver results. But progress has been slow. Global emissions of CO_2 have risen annually by 2.5 percent while decarbonization, that is the reduction in carbon released per unit of output, has fallen by 1.5 percent per annum. Current projections indicate that the Paris Agreement will not achieve the desired degree of decarbonization, and pledges without enforcement will not work. Figure 5 presents a view on where the world is, where it is heading, and what could be achieved by strong, enforceable policies.[53]

The 6th Assessment by the IPCC to be issued in 2022 should provide policymakers meeting for the "stock-take" in 2023 with compelling evidence to make binding commitments. As examined in the next section, coming to grips with climate change calls for greater clarity regarding objectives and instruments and mechanisms of enforcement. Deferring action is no longer a viable option, however unpalatable the cost of bending the trajectory of emissions might seem to politicians, businesses, and the public. The painful shock administered by the COVID-19 pandemic bears no comparison to the kind of pain that accelerating climate change would inflict on all countries—with EMDEs squarely in the eye of the storm.[54]

Figure 5: Climate change scenarios



Source: Cornwall (2020).

1.2. Negotiating Climate Agreements Has Been an Uphill Task

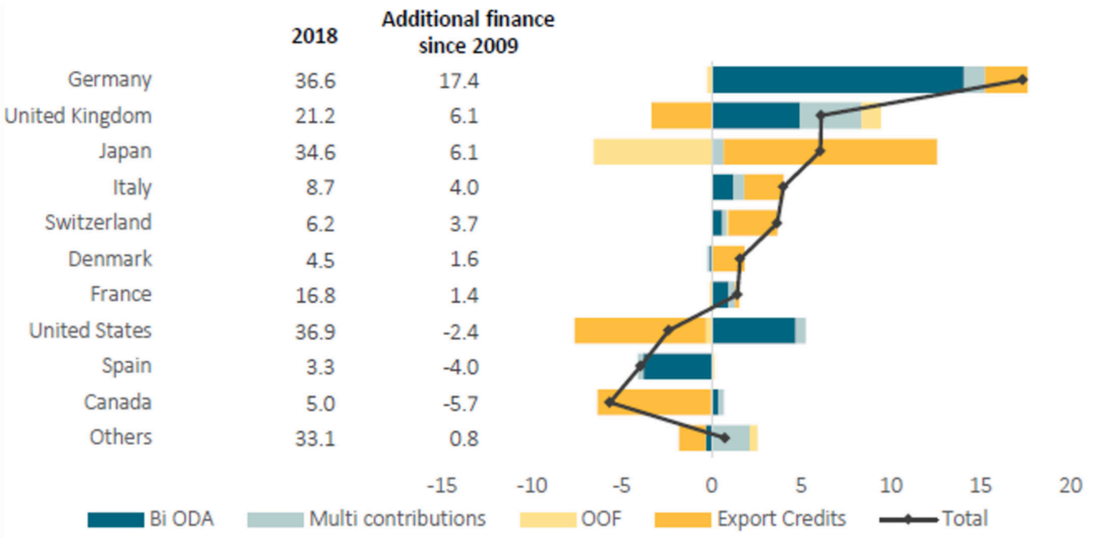
Nations have struggled to agree on the specifics of a binding climate agreement for a variety of reasons. Three have proven especially troublesome and will need to be addressed if the global community is to collectively adopt measures that will lead to net zero emissions by the middle of the century or soon thereafter. The three are: financial support for the additional costs that will be incurred by developing countries; clarity regarding the measurement of net zero emissions; and credible means of monitoring emissions and penalizing countries that deviate from their pledges.

Developing countries have argued that they are not responsible for much of the carbon pumped into the atmosphere since the start of the industrial revolution. They further insist that a rapid greening of development would be costly and that they are owed some compensation by the countries largely responsible for the bulk of past and current emissions. In 2009, industrialized countries agreed to "new and additional" financing for developing countries amounting to US$100 billion to defray the burden imposed by measures taken to control emissions.[55] This commitment was reaffirmed by Article 9 of the Paris Agreement.

This additional financing has been slow to materialize. Between 2009 and 2018, the OECD estimated that US$79 billion in new assistance from bilateral, multilateral, and private sources was provided to developing countries.[56] However, the actual amount of new financing may be much lower. According to one estimate, 45 percent of the total were existing resources that had been rebadged or reallocated for climate change related purposes.[57] Moreover, several countries including the United States and Canada, cut back their assistance in the aggregate.

This has contributed to tensions between developed and developing nations and led to an erosion of trust. Figure 6 offers a snapshot of the financing from various sources.

Figure 6: Total development finance



Source: Mitchell et al. (2021).

At the next round of negotiations in 2023, countries will need to arrive at a clearer delineation of climate financing and how such spending is reported and accounted for[58] plus an agreement on how the resource needs of developing countries will be met. Advanced economies must come forward with some of the financing—possibly in excess of the US$100 billion promised earlier. Still, this will not suffice. Developing countries will need to mobilize additional resources domestically; and those with the relevant capability could make up for a shortfall by tapping international financial markets. This is a point we will return to in section 3.

How emissions are defined and what the plans countries have tabled raises a second set of thorny issues. Roeglj et al. (2021)[59] draw attention to some fundamental ambiguities inherent in net zero labelling. This is because some countries such as China refer only to emission of CO_2. The EU is targeting net zero emissions of all GHGs. The United States has not specified what kind of emissions it intends to control. Corporate entities are only committing to reducing emissions they can control or at best emissions released by their supply chains. Some are using offsets to meet targeted reductions.

Outcomes depend somewhat on which GHG are mitigated. As Roeglj et al. (2021) explain, "CO_2 is the main cause of rising global temperatures; it accumulates and lasts [in the atmosphere for] thousands of years. Bringing CO_2 emissions down to net zero halts further warming, but the impact of CO_2 already present in the atmosphere will linger for centuries. By contrast, shorter-lived greenhouse gases, such as methane [and fluorinated gases[60]], last for years to decades. Reducing these would diminish their contribution to warming relatively quickly."

To resolve the issue, the Paris Agreement encompasses all greenhouse gases. Non-CO_2 gases that cannot be eliminated must be offset by an equivalent cutback of CO_2 emissions using whatever means are available, including carbon capture and sequestration (CCS). The metric adopted by the UN to determine this equivalent amount is the greenhouse gas Global Warming Potential over 100 years, or GWP-100.[61] Currently, net zero targets lack credibility because countries have not been forthcoming with "milestones, an implementation plan, and a statement about longer-term intent for either maintaining net zero or going net negative. Leaving these out risks inaction, diversions and failure" (Roegli et al. 2021). The inconclusive outcome of COP 25 held in December 2019 points to holdups to come. However, the preparation of national plans in time for COP 26 and the creation of a Sustainable Standards Board offers hope of progress.

The third issue to be resolved is the enforcement of pledges and the need to minimize free riding.[62] The attempts to significantly check the increase in emissions have fallen short of expectations because although the vast majority of UN members have signed on to climate agreements, there is no obligation to adhere to paper commitments. No country is penalized if it fails to comply.[63] Devising an enforcement mechanism that the leading emitters would buy into is no easy task. One possibility with support was proposed by William Nordhaus (2015) and calls for the formation of a climate club or a compact.[64] Members would set a price on carbon,[65] coordinate with each other, and adhere to clearly defined targets for GHG emissions. Members would also commit to imposing "carbon border adjustment tariffs" on imports from non-members based on the carbon emitted in the manufacturing process.

A climate club comprised of the United States, the EU, and possibly China (the three account for close to 45 percent of global imports) could incentivize other countries to join so as to avoid the levies on their exports to club members. It would also minimize carbon leakages resulting from a transfer of production activities to countries with less stringent regulation and monitoring of emissions. As the cost of controlling emissions declines, the membership of the club would expand. And in fact, with renewable sources generating electricity at lower levelized costs than coal-fired plants and other technologies offering cost-effective ways of reducing emissions from industry, transport, and buildings, a climate club comprised of the advanced countries and China would induce other trading nations to do what was necessary to gain admission.

A climate club constitutes one of several measures that could motivate compliance. These include financing (noted earlier), technology transfer, capacity building, and the use of litigation that puts legal pressure on governments and corporations to provide compensation for damages inflicted by emissions. Monitoring compliance and designing credible incentives and sanctions is a challenge.[66] But no climate agreement will deliver the urgently needed results if adherence by sovereign participants is purely voluntary, each country chooses its own not especially exacting emission target, and a pledge by one regime can be ignored by its successor.[67] The major emitters must lead by example, by living up to their commitments to other countries, and by strengthening not undermining climate change governance.[68]

These are some of the knots that negotiators must untangle in the next couple of years. The stakes are high. Failure to arrive at binding pledges on emissions and assistance for developing countries will be costly for all and more so for economies lower on the income ladder as reviewed in the section 2.

2. Climate Change Burdens and Needed Responses

The impacts of unmitigated climate change have been made clear by a succession of IPCC reports and a veritable library of other writing and research. Climate change poses a threat to the availability of fresh water, agricultural yields, labor productivity, and health, and will likely lead to mass migration and to political instability.

2.1. Ensuring Food Security

Feeding the world's population (forecast to approach 10 billion by 2050) will be a huge undertaking in a warming environment, given that food systems already appear to be under stress.[69] Two thirds of all calories consumed are sourced from four crops: wheat, rice, maize, and soybeans. This simplification and homogenization of crop production enhances the vulnerability of the global food production system to shocks. Higher temperatures are taking a toll on productivity. Test results show that every one-degree Celsius increase in global mean temperature reduces yields of wheat by 6.0 percent, rice by 3.2 percent, maize by 7.4 percent, and soybean by 3.1 percent.[70] According to field experiments by Peng et al. (2004), rice yields fell by 10 percent for every 1°C rise in temperatures. The yield of corn in the United States begins to trend downwards when temperatures rise above 29°C, of soybeans once it exceeds 30°C, and a temperature above 32°C depresses the yield of cotton crops (Schlenker and Roberts 2008).

The anticipated decline in yields of corn, wheat, rice, soybeans, cotton, and sorghum is reaffirmed by the U.S. Global Change Research Program (2018, p.41).[71] For example, in West Africa a 1°C increase in mean temperatures is responsible for reduced yields of millet (10–20 percent) and sorghum (5–15 percent).[72] Furthermore, the nutritional content of C3 plants will be lower as the CO2 prevalence in the atmosphere rises (when CO2 rises to between 546–586 ppm, wheat has 5.9–12.7 percent less protein, 3.7–6.5 percent less zinc, and 5.2-7.5 percent less iron).[73] Most other major crops will be similarly affected not just by warming, but also by the increased prevalence of disease, invasive plants and pests,[74] dust, short-lived climate pollutants (ozone, black carbon), the disappearance of many pollinators, water stress (including from groundwater depletion and dissolved oxygen content), a reduction in food quality, and the increased risk of spoilage as well as of infestation by mycotoxins.[75] Africa (and Asia) could be especially hard hit with a 50 percent loss of agricultural output (Porter et al. 2014).[76] Pastoral farming and aquaculture (disease, parasites, toxic algae) would not be spared. In fact, loss of pasture, lower animal productivity, disease, and biodiversity loss would impose large costs.

Overall, the annual reduction in consumable calories traceable to climate change may amount to one percent of the total or 35 trillion calories, which could worsen malnourishment, stunting, and wasting, which are still widely prevalent in developing countries.[77] Food security will become a major concern for most developing countries with low-income consumers bearing the brunt.[78] Because of climate change, population growth and per capita caloric consumption (which rose through the last third of the 20th century) would begin to decline (Figure 7). As it is, close to two thirds of the population in Sub-Saharan Africa (SSA) cannot afford a healthy diet.[79] More than 2 million children under the age of five die from hunger and related illnesses each year, as well millions of older children and adults. Many more suffer from wasting and stunting and from deficiencies of micronutrients.[80] Climate change will increase that percentage and not just in SSA.

Figure 7: Global and regional per capita consumption (kcal per capita per day)

Region	1964-1966	1974-1976	1984-1986	1997-1999	2015	2030
World	2358	2435	2655	2803	2940	3050
Developing countries	2054	2152	2450	2681	2850	2980
Near East and North Africa	2290	2591	2953	3006	3090	3170
Sub-Saharan Africa[a]	2058	2079	2057	2195	2360	2540
Latin America and the Caribbean	2393	2546	2689	2824	2980	3140
East Asia	1957	2105	2559	2921	3060	3190
South Asia	2017	1986	2205	2403	2700	2900
Industrialized countries	2947	3065	3206	3380	3440	3500
Transition countries	3222	3385	3379	2906	3060	3180

Source: https://www.who.int/nutrition/topics/3_foodconsumption/en/.
a. Excludes South Africa.

The IPCC report has laid out a long list of remedies to mitigate the consequences of declining yields and wastage across the food value chain. Among these, biogenetic, nano-chemical, mechanical, and digital technologies will undoubtedly play a major role, as will improvements in transport, the cold chain, and storage technologies[81] for grain and other products. Advances in each of these areas have been ongoing with biogenetic and digital innovations appearing thick and fast in recent years. Molecular biologists using DNA editing techniques such as CRISPR-Cas9 and TALEN are beginning to develop variants of cultivars with disease- and drought-resistant qualities more swiftly and efficiently.[82] Nanotechnology is helping scientists calibrate the use of inputs to maximize yields.[83]

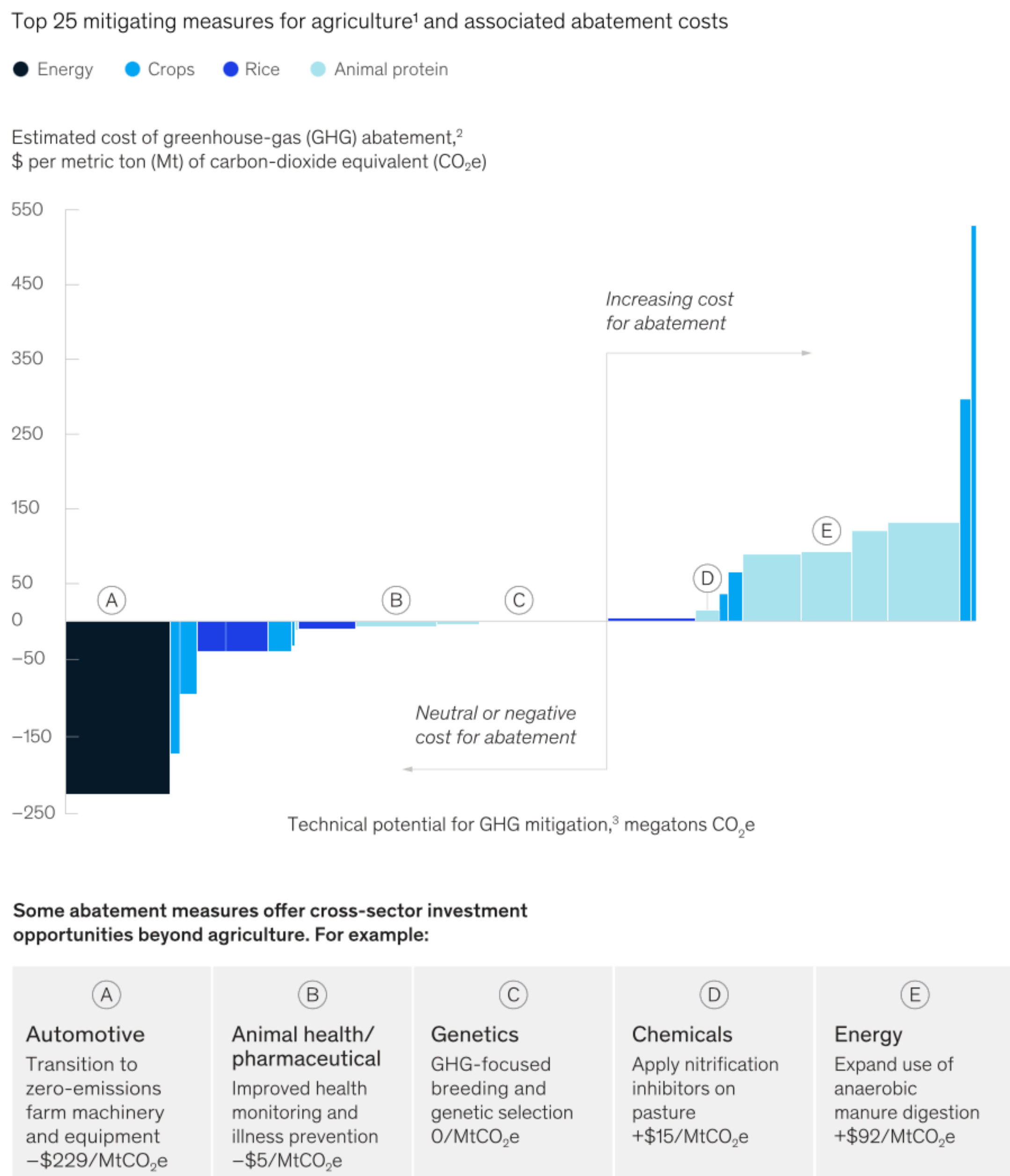
The mechanization of agriculture is accelerating. New smart machines using digital technologies/Big Data are enabling precision agriculture that conserves inputs (including energy and water)[84] by using them in a targeted and precisely calibrated manner with the help of numerous sensors. Smart machines, in conjunction with improved crop varieties and new weeding and harvesting equipment, also enhance yields.[85] These technologies are optimized for the conditions, resource endowments, and crops of upper middle- and high-income countries and may currently seem beyond the reach of many developing countries lacking the human and physical capital. However, adaptive innovations can harness them in forms appropriate for developing country environments. Such innovation is going to become a necessity in order to minimize losses of output and the risk of acute food crises. Other techniques and changes in cropping practices will reduce emissions of CO2, methane, and nitrous oxide.[86]

There is no time to lose in building the research, digital, extension, and physical infrastructure to adapt and mainstream new agricultural technologies. Speedy development will demand scaled-up resource mobilization and investment, well above current levels. A report prepared by the Food and Land Use Coalition offers a roadmap to a more sustainable agriculture, which includes a transition to a more plant-based diet and reduction of costly externalities inflicted by current practices.[87] Figure 8 presents some estimates of the costs of GHG abatement in agriculture, with reduced consumption of animal protein being the priciest.

2.2. Securing Adequate Supplies of Water

Fresh water availability underpins agricultural and industrial[88] productivity, and is a determining factor in the survival, growth, and quality of life of urban centers. MIT researchers project that “domestic freshwater consumption could double from 348 billion cubic meters in 2010 to 698 billion cubic meters in 2100, and industrial use of water could increase from 763 billion cubic meters to 1,098 billion cubic meters, or about 45 percent. Irrigation use is projected to decline slightly worldwide.”[89]

Figure 8: Cost of abatement measures to reduce GHG emissions from agriculture



Source: Aminetzah, Katz, and Mannion (2020).

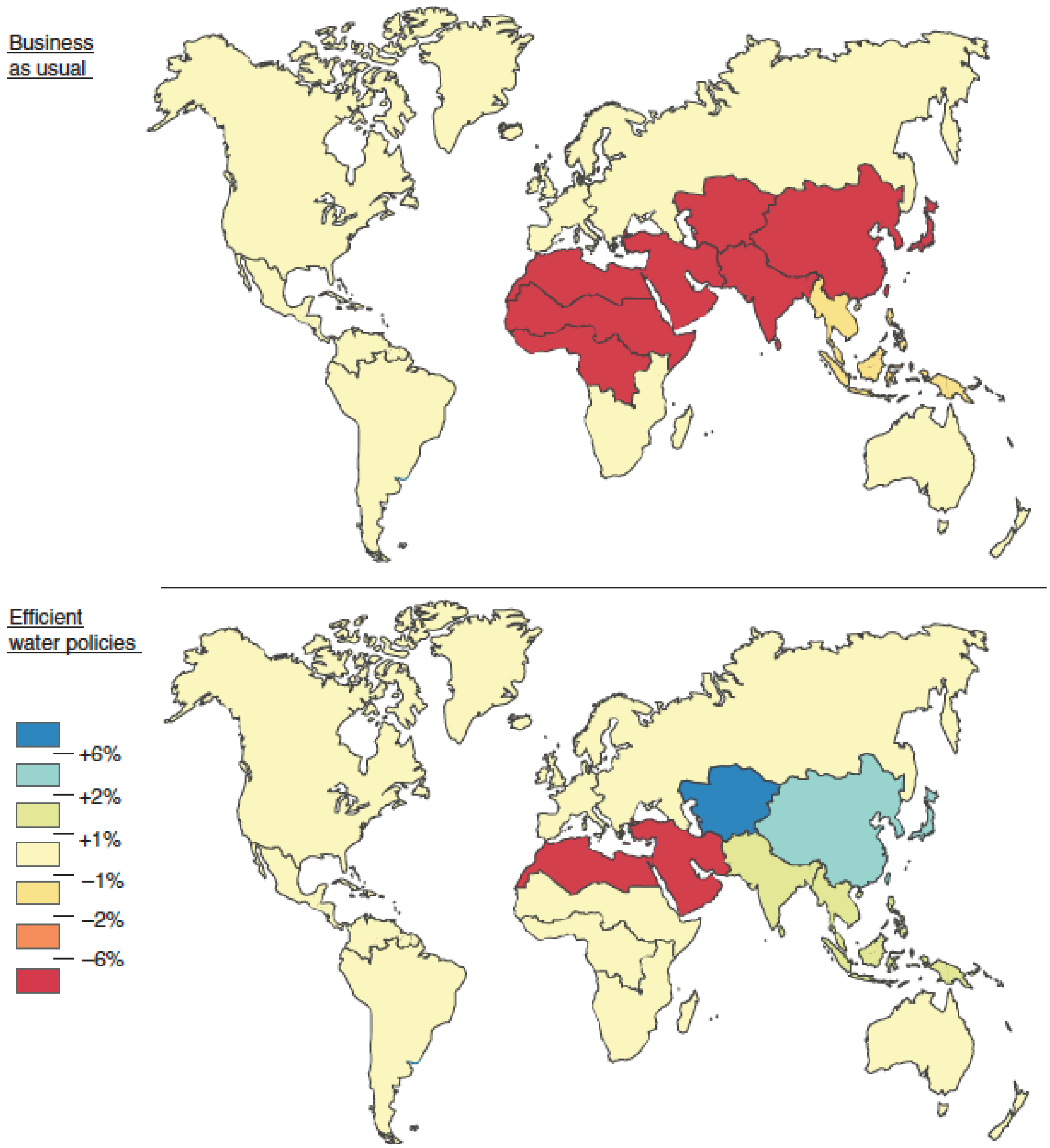
However, water availability is likely to fluctuate and decline even as demand and competition among users increases. Usable water resources are affected by precipitation, snowmelt, evaporation, groundwater levels, and dissolved oxygen content. Satellite imagery collected by NASA from 2002 to 2016 indicates that drier areas are becoming even more dry and those that are wet have become wetter.[90] The IPCC estimates that when the global mean temperature rises by one degree, 7 percent of the population experiences a 20 percent decline in renewable water availability. This warming could happen as soon as 2025,[91] or by 2067 in a more temperate assessment.[92]

Warming will also lead to more frequent extreme weather events and social disruption. The population exposed to 100-year floods will rise threefold.[93] Drought increases the risks from wildfires and conflicts, which in turn can trigger large-scale migration. According to some commentators, severe drought and crop failures in Syria starting in 2007 accelerated migration from rural areas to cities. This drought-related migration is considered one of the factors (including other political forces) precipitating unrest, full-fledged civil conflict, and refugee migration into neighboring countries.[94]

Water scarcity is growing in many Asian, African, and Middle Eastern countries. Down the road, the World Bank estimates that the more severely affected regions could lose 6 percent or more of GDP.[95] The Northern part of China is a water-scarce region where the situation is likely to worsen over time as supplies diminish.[96] Among the Middle Eastern nations, Jordan is already one of the most water-poor countries and exemplifies the risks from climate change. Warming could lead to a sharp reduction in water supplies from all sources, including the Yarmouk River, even as the population balloons because of natural increase and an influx of migrants.[97] Drought and water politics[98] also threaten countries that depend on the Mekong River—principally, Vietnam, Cambodia, and the Lao People's Democratic Republic.[99]

India’s situation highlights the severity of the emerging problem for others. The Northern part of the country is reliant on rivers that originate from the Tibetan Plateau and are fed by melting snowpack as the make their way through the Himalayas down to the plains. Melting glaciers and a decline in snowfall could reduce river flow in the summer and fall, increasing dependence on monsoon rains. More than 20 cities are already facing acute water shortages, including Bangalore, Delhi, and Chennai.[100] River and groundwater pollution are seriously degrading potable water quality and are the cause of 200,000 deaths annually. Satellite and ground observations point to continuing depletion of groundwater as a result of excessive pumping in the Northern and Eastern parts of the country.[101] And a combination of warming, population growth, and urbanization could mean that 40 percent of India’s population will not have access to drinking water by 2030—half a billion people.[102] With less water for bathing, hand washing, and cooking, gastrointestinal and other diseases could run rampant.[103] The effects of water scarcity on GDP by 2050 under a business-as-usual scenario versus a good policy scenario is shown in Figure 9.

Figure 9: Effects of water scarcity on GDP in 2050 under two different policy regimes



Source: World Bank calculations.
Note: The top map shows the estimated change in 2050 GDP due to water scarcity, under a business-as-usual policy regime. The bottom map shows the same estimate, under a policy regime that incentivizes more efficient allocation and use of water.

Source: World Bank (2016).

Addressing water scarcity related to climate change will require more efficient utilization of water resources. Mitigations will include efficient pricing policies, conservation measures, investment in water transport and storage infrastructure that minimizes losses, investment in power-generating facilities to operate pumps and recycling facilities,[104] and frugal water standards for equipment in homes and factories.

Policy measures to improve the efficiency with which water is utilized and conserved have a long and checkered track record. For example, assigning water permits allows recipients to use, rent, or trade water, but the optimal assignment is a legally complex, institutionally demanding, and politically burdened process. Water permitting needs to take account of the shift in water use from agriculture to the urban sector, as well as the implications of rainfall variability resulting from climate change.

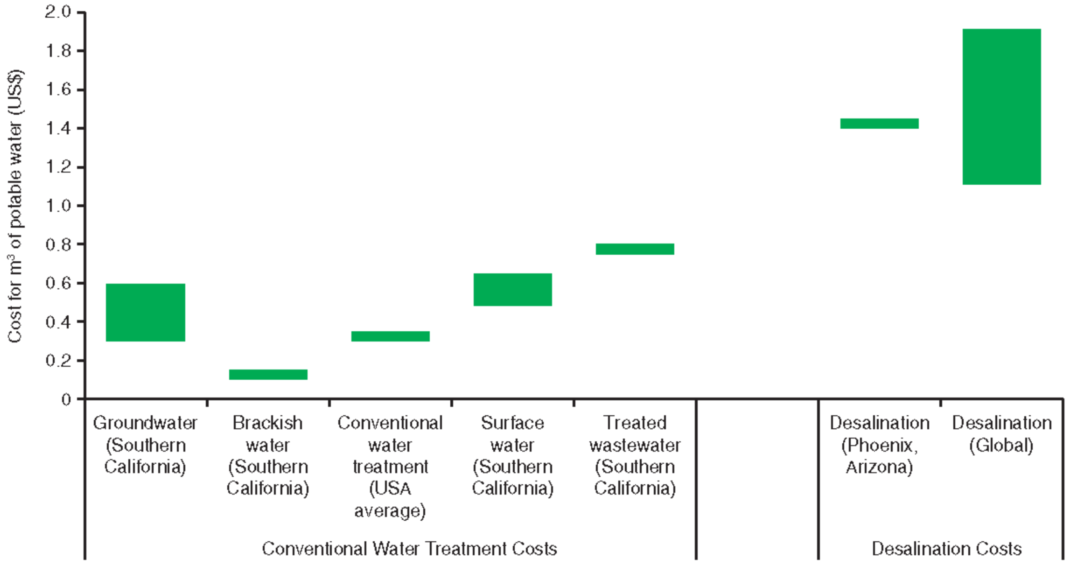
Pricing water to reflect its scarcity (with adjustments so as not to burden the poor) has a strong economic pedigree. Moreover, where utilities are required to cover costs, they have an incentive to minimize inefficiencies such as leakage. But pricing runs into a political thicket when agricultural users are called upon to pay water charges. Their resistance is fierce in every country and is compounded by the difficulty of metering water usage and controlling the pumping of groundwater. Nevertheless, given the high share of water consumed by agriculture and the widespread evidence of waste, this is a nettle governments must grasp. There remain "opportunities to alter behavior and change thirsty consumption patterns through education, contextual cues, and using social norms to signal consent or disapproval."[105]

Technology that reduces the energy and other costs of recycling and desalinating water and that drastically cuts the water consumed by farms, factories, and power plants[106] will be a necessary complement to water pricing.[107] Globally, 70 percent of water is used for agricultural purposes[108]—more in low-income/lower middle-income countries (over 80 percent in Africa and Asia) and significantly less in high-income ones (41 percent, 21 percent in Europe, and 51 percent in North America).[109] Industry accounts for 19 percent, and households for the balance (11 percent).

Developing countries need to invest in technologies related to water recycling and the desalination of brackish water and seawater.[110] For example, researchers are developing new membranes using graphemes and carbon nanotubes. To reduce energy consumption, forward osmosis and reverse osmosis/pressure-retarded osmosis are being piloted as are techniques to recapture some of the energy from fluid streams.[111] Energy consumption by desalinating plants has declined by 80 percent over the past two decades, but the potential for improvement is far from exhausted.[112] Recycling water to drinking-quality standards or lesser levels suitable for irrigation, industrial, and groundwater recharge purposes may have even more potential and will be a needed technology in many inland areas far from water courses.[113] Figure 10 compares the costs of supplying water from a variety of sources and using various technologies.

As with agriculture, assuring adequate supplies of potable water is going to be a costly challenge. The scope for innovation using physical, chemical, and biological means is ever expanding as removing all solids (e.g., microplastics) and contaminants from water is beyond the reach of many existing technologies (at an affordable cost).[114] Countries will need to prepare for investments in both physical facilities and in accumulating usable knowledge to advance the technological frontier.

Figure 10: Cost of water production by source



Source: World Bank (2016).
Note: Desalination calculated as an average of costs from 12 large urban areas around the world.

2.3. Strengthening and Building Infrastructure

Coastal areas, island nations such as the Maldives, people living in floodplains, and those inhabiting areas near the wildland interface[115] are increasingly exposed to severe weather events, fires, and floods. The costs in terms of property damage and lives lost is tracking this rise. A continuation of warming (likely to exceed 1.5°C) will mean that these areas will remain highly exposed to buffeting by the elements.

Coastal areas and locations alongside rivers have long been favored for settlement because the climate is milder, water-borne transport is convenient and cheap, and rivers provide fresh water and can be a way of disposing waste. Hence many of the world's largest cities are situated on waterways or along the coast. Forty percent of the world's population lives within 100 kilometers of a coastline and 600 million or more in low-elevation coastal zones (10 meters above sea level or less[116]). The bulk of economic activity is concentrated in coastal areas or along waterways. Expanding populations and cityward migration in developing countries will result in greater concentration in zones potentially vulnerable to climate change.

In order for potentially exposed areas to remain habitable and to sustain or improve current levels of economic activity, the infrastructure will have to be made climate resilient.[117] This will be a huge and evolving undertaking. Climate-modelling exercises can inform planning, but much uncertainty remains about future trends in global and regional temperatures. There is also uncertainty about the severity of weather events, and vigorous debate about how best to climate proof key infrastructures. Looming over the variety of options—very few for some of the most vulnerable developing nations—is the cost. The data needed for effective decision making and the (modelling, planning, design, standard setting, and regulatory) tools are improving in developed countries but developing ones lag far behind.[118] Financial tools are also evolving, and climate-related financing is bound to grow vertiginously in the future.

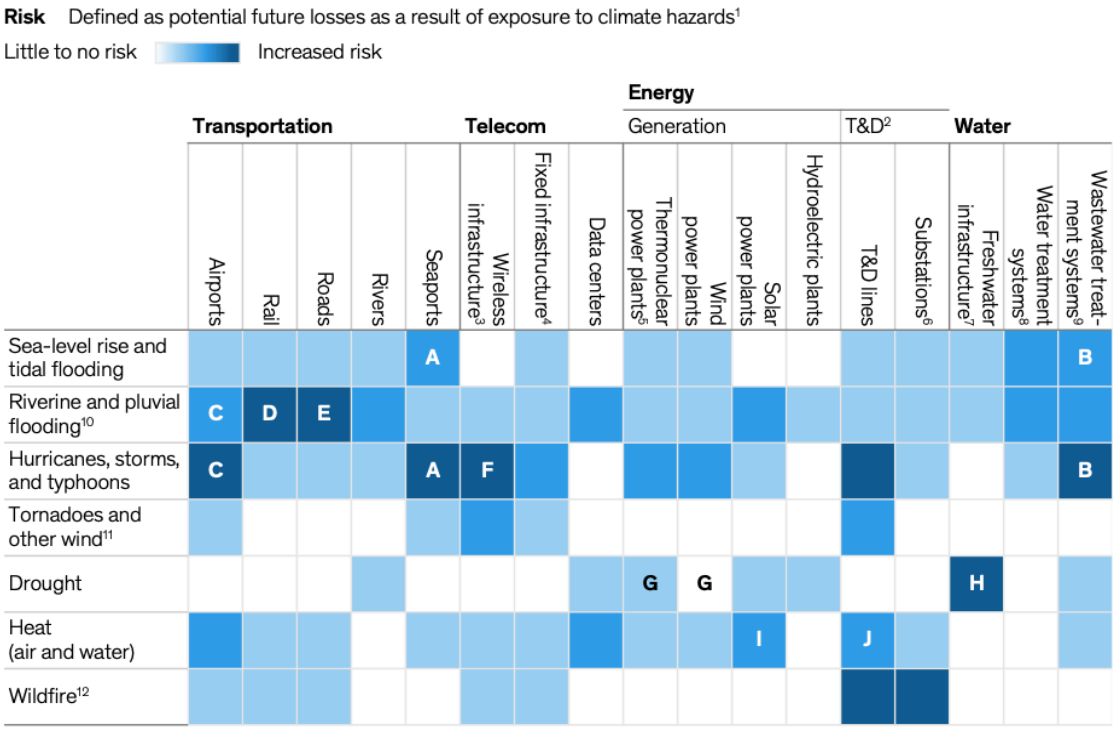
In terms of scope and scale, climate proofing of soft and hard infrastructures presents significant challenges for developing countries. Cities such as Saigon/Ho Chi Minh City, Bangkok, and Jakarta have been pumping groundwater for decades, but they are still sinking each year and the threat from flooding has grown.[119] Cities in this predicament[120] can combat rising sea levels by building sea walls and combining them with natural barriers—including preservation, where feasible, of coastal wetlands, marshes, and mangrove forests.[121] In addition, drainage and pumping systems will have to be strong enough to protect against flooding, and the water and sewerage systems will need proofing against a rising water table and the worsening salinity of groundwater from seawater incursion. Coastal areas have already begun elevating roadbeds and railway tracks in line with storm-hardening evaluations. Buildings most at risk can be strengthened by adding concrete reinforcement or by constructing a concrete or masonry wall on the perimeter of the property.[122] This work, along with advances in the materials used and the quality of construction, will become a necessity for new transport infrastructure and the upgrading of legacy infrastructures.

Severe weather events and natural disasters in the past decades have demonstrated that infrastructure built to specifications determined by past weather patterns is unsuited for conditions that will prevail as the climate warms.[123] Hurricane Sandy, which pummeled New York and New Jersey in 2012, exposed the vulnerability of key urban systems. Subways were flooded, low-lying electrical equipment was disabled, power lines were downed,[124] cell phone towers collapsed, the stormwater drainage system was overwhelmed, and sewerage systems were compromised. Similarly, the damage inflicted to homes by wildfires in California and Washington State has revealed the vulnerability of the electric power infrastructure. Drought, a perennial and now increasing worry in the Middle East, North Africa, and in parts of the India subcontinent, could also wreak havoc, especially when accompanied by heatwaves. Figure 11 indicates the level of risk to infrastructures arising from severe weather events. Flooding and hurricanes cause the most damage.

Despite the growing need for climate proofing, there is widespread neglect of infrastructure. Existing infrastructure is aging and replacement rates are low and slipping further. The state of the transportation system in the United States and the magnitude of the investment requirements are a warning to other nations. Of the 616,087 bridges in the United States, 235,000 require structural rehabilitation, repair, or removal. The conservatively estimated price tag for rehabilitation is US$171 billion.[125]

The demand for and the cost of more and better infrastructure is set to rise over the next three decades.[126] With climate change, the cost of providing this infrastructure could escalate by 10–15 percent and there are no substitutes or technological shortcuts. In order to minimize GHG emissions, the infrastructure must be built accordingly and made suitably resilient. The good news is that some EMDEs are beginning to spend 4.5 percent of GDP, which could suffice under the preferred scenario in a recent World Bank report (see Figures 12 and 13).[127] However, this is by no means a settled view. Other estimates point to a wider infrastructure gap (US$15 trillion through 2037 on current trends), and to misallocated investment generating low returns.[128]

Figure 11: Vulnerability of infrastructure assets to climate change



A. Seaports, by definition, are exposed to risk of all types of coastal flooding. Typically, seaports are resistant and can more easily adjust to small sea-level rise. However, powerful hurricanes are still a substantial risk. In 2005, Hurricane Katrina destroyed ~30% of the Port of New Orleans.

B. Wastewater treatment plants often adjoin bodies of water and are highly exposed to sea-level rise and hurricane storm surge. Hurricane Sandy in 2012 led to the release of 11 billion gallons of sewage, contaminating freshwater systems.

C. Many airports are near water, increasing their risk of precipitation flooding and hurricane storm surge. Of the world's 100 busiest airports, 25% are less than 10m above sea level, and 12—including hubs serving Shanghai, Rome, San Francisco, and New York—are less than 5m. Only a few mm of flooding is necessary to cause disruption.

D. Rail is at risk of service interruption from flooding. Disruption to signal assets in particular can significantly affect rail reliability. Inundation of 7% of the UK's signaling assets would disrupt 40% of passenger journeys. Damage can occur from erosion, shifting sensitive track alignments.

E. Roads require significant flood depths and/or flows to suffer major physical damage, but incur ~30% speed limitations from 0.05m inundation and can become impassable at 0.3m. Compounding effects of road closures can increase average travel time in flooded cities 10–55%.

F. Cell phone towers are at risk from high wind speeds. During Hurricane Maria in 2018, winds of up to 175mph felled 90+% of towers in Puerto Rico. Risks are more moderate at lower wind speeds, with ~25% of towers downed by ~80mph winds during Hurricane Sandy.

G. Wind power plants are highly resistant to drought; thermoelectric power plants, which regularly use water for cooling (seen in >99% of US plants), are at risk during significant shortages.

H. Freshwater infrastructure and associated supplies are highly vulnerable to impact of drought, as seen when Cape Town narrowly averted running out of drinking water in 2018.

I. Solar panels can lose efficiency through heat, estimated at 0.1–0.5% lost per 1°C increase.

J. Transmission and distribution suffers 2 compounding risks from heat. Rising temperatures drive air conditioning use, increasing load. Concurrently, heat reduces grid efficiency.

Source: McKinsey (2020).

Figure 12: Infrastructure development scenarios

Average annual cost to develop infrastructure for the preferred scenario and full range of results, by sector, 2015–30

	Electricity	Transport	Water supply and sanitation	Flood protection	Irrigation	Total
Minimum spending scenario: less ambitious goals, high efficiency						
	Strongly reduce demand for energy through energy efficiency measures; invest now in renewable energy and energy efficiency; gradually ramp up access in poorest areas	Increase the utilization rate of rail and public transport; densify cities; reduce demand for transport	Provide only basic water and sanitation	Keep coastal flood risk constant in relative terms; accept increased risks from river floods based on cost-benefit analysis	Subsidize irrigation infrastructure only; promote low-meat diets	2.0% of GDP (US$640 billion)
	US$298 billion 0.90% of GDP	US$157 billion 0.53% of GDP	US$116 billion 0.32% of GDP	US$23 billion 0.06% of GDP	US$43 billion 0.12% of GDP	
Preferred scenario: ambitious goals, high efficiency						
	Invest now in renewable energy and energy efficiency; gradually ramp up access to electricity in poorest areas	Increase the utilization rate of rail and public transport; densify cities; promote electric mobility	Provide safe water and sanitation using high-cost technology in cities and low-cost technology in rural areas	Adopt Dutch standards of coastal flood protection for cities; accept increased risks from river floods based on cost-benefit analysis	Subsidize irrigation infrastructure only	4.5% of GDP (US$1.5 trillion)
	US$778 billion 2.2% of GDP	US$417 billion 1.3% of GDP	US$198 billion 0.55% of GDP	US$103 billion 0.32% of GDP	US$50 billion 0.13% of GDP	
Maximum spending scenario: ambitious goals, low efficiency						
	Do not invest in energy efficiency or demand management; provide high access to electricity using fossil energy for 10 years and early-scrap these capacities to switch to low carbon	Let cities sprawl; favor rail investments without accompanying policies to increase the utilization rate of rail	Provide safe water and sanitation using high-cost technology everywhere	Adopt Dutch standards of coastal flood protection for cities; keep river flood risk constant in absolute terms	Subsidize both irrigation infrastructure and electricity for water extraction	8.2% of GDP (US$2.7 trillion)
	US$1,020 billion 3.0% of GDP	US$1,060 billion 3.3% of GDP	US$229 billion 0.65% of GDP	US$335 billion 1.0% of GDP	US$100 billion 0.20% of GDP	

Source: Rozenberg and Fay (2019).

Figure 13: Cost of development infrastructure in the base case scenario

Average annual cost of investment in the preferred scenario, by sector and region, 2015–30

% of regional GDP

		SSP region									
		Africa and Middle East	Asia	Latin America and Caribbean[a]	Former Soviet Union[b]	World Bank region					
Sector	**Type of investment**					**Middle East and North Africa**	**Sub-Saharan Africa**	**South Asia**	**East Asia and Pacific**	**Latin America and Caribbean**	**Eastern Europe and Central Asia[b]**
Electricity	Capital	1.3	2.4	1.2	5.3						
	Maintenance	0.3	0.7	0.2	1.1						
Transport	Capital	3.2	0.8	1.4	0.0						
	Maintenance	1.0	1.6	0.6	1.8						
Water supply and sanitation	Capital					0.9	1.6	0.8	0.3	0.5	0.4
	Maintenance					0.3	0.6	0.3	0.1	0.2	0.1
Irrigation	Capital[c]					0.1	0.4	0.3	0.1	0.1	0.0
Flood protection	Capital					0.2	0.8	0.5	0.3	0.2	0.06
	Maintenance					0.04	0.11	0.07	0.08	0.08	0.01
Total[d]	Capital					5.6	7.2	4.8	4.0	3.4	
	Maintenance					1.6	2.0	2.7	2.5	1.1	

Note: Country groups differ between sectors due to the different regional aggregation of models used. SSP = shared socioeconomic pathway, as used by the Intergovernmental Panel on Climate Change.

a. The following countries and territories are included in the SSP country group, but not in the World Bank country group: Aruba, The Bahamas, Barbados, Chile, French Guiana, Guadeloupe, Martinique, and Uruguay.

b. The Russian Federation is included in the SSP Former Soviet Union group, but not in the World Bank Eastern Europe and Central Asia group because it is classified as a high-income country.

c. Includes maintenance.

d. Based on countries that are included in all studies.

Source: Rozenberg and Fay (2019).

Financing additional infrastructure investments is challenging for developing countries, which often face preexisting infrastructure gaps, inefficient provision of infrastructure services, and a myriad of competing short-term expenditure needs. In particular, SSA lags the developing world in nearly all dimensions of infrastructure performance. Financing infrastructure that can withstand climate change will require "not only more efficient domestic resource mobilization from SSA governments, but also innovative solutions to crowd-in private financing."[129]

Given the exigencies of climate change, a radical rethink of development financing may be required as existing instruments such as official development assistance (ODA) and green bonds may not suffice. Developed economies may have difficulty meeting existing commitments, including laudable goals such as the SDGs, let alone dealing with climate change exigencies and narrowing infrastructure gaps. Some climate-related innovation in ODA is evident. For example, ESMAP, supplemented by financing from the Climate Investment Fund and Green Climate Fund, is supporting the development of green energy.[130] The Global Environment Fund and the Special Climate Change Fund address climate change needs. But these changes are not enough to close the gap. Climate finance discussion seems to coalesce around the idea of a mega-fund that is (i) large enough to wean economies from fossil fuel-based energy systems, and (ii)more democratic in its governance structure.[131] Although few governments will be eager to contribute to a new mega-fund, an initiative led by key development agencies that attracts matching investments from the private sector could mobilize the tens of billions that developing countries need.

2.4. Sustaining Labor Productivity

A substantial body of research shows that labor productivity peaks at 13°C. As workplace temperatures rise, productivity first plateaus and then declines by 2 percent per degree increase over 22°C or 25°C depending on activity.[132] In the United States, Deryugina and Hsiang (2014) find that labor productivity slips by 1.7 percent for every 1°C increase in average temperature above 15°C. Exports and industrial value added also decrease by between 2 percent and 2.4 percent for every degree increase over the average for the year.[133] Services output in the Caribbean falls by 6 percent.[134] Moreover, rising temperatures quickly register on the GDP bottom line: each degree increase over the annual average can shave between 2–3 percent off per capita GDP.[135] This implies that positive growth can quickly be erased by rising temperatures through the labor productivity factor. Ignoring these trends will only serve to tip developing countries into increasingly precarious economic circumstances.

Inevitably, it is the poor who suffer the most from rising temperatures. They tend to live in the most heat-prone areas within and among countries, and also are more likely do work that exposes them to higher temperatures (agriculture, transport, refuse collection, construction, manual work).[136] Intra-country inequality has been on the rise in many EMDEs and warming appears to be exacerbating this trend[137] because of (i) exposure of low-income groups to climate change; (ii) greater susceptibility of this income group to the damage from climate change; and (iii) and climate change diminishes their ability to cope and recover.[138]

A warming climate will entail major changes in the scheduling of work with more being done early in the day and in the evenings. However, much more than this will be required to sustain economic activity, in particular temperature control in work (and living) environments for workers in industrial and services sectors. Air conditioning on a broad scale—as in Singapore—is a possibility, but it is currently a costly, energy intensive solution, which few developing countries can afford.[139] The Singapore economic 'miracle' would have been inconceivable without widely available air-conditioning.[140] Widespread adoption of affordable cooling techniques with minimal increase in carbon emissions requires advances in technology (passive and other), optimized design of urban spaces, and electricity from renewable sources.

The demand for space cooling could increase threefold by 2050 and account for 37 percent of the electricity consumed.[141] Technological gains in three areas could bring climate control on a large scale within reach of low- and middle-income countries while curtailing carbon emissions. The first area of technological advance is in cooling technologies. Technologies currently in use include "sorption cooling, desiccant cooling, magnetic cooling, thermoacoustic cooling, thermoelectric cooling, and trans critical CO_2."[142] Developing these further and finding other less pricey options should be (and is becoming) one area of intensive research.[143]

The finalists for the Global Cooling Prize[144] have come forward with a number of innovative solutions. These include "Smart hybrid technology to optimize on efficiency and handle temperature and humidity separately; no or low-GWP (global warming potential) climate-friendly refrigerants; reusing system-generated waste heat and water; smart controls, sensors, and automation to optimize hybrid operation based on outdoor and indoor conditions; or integration of a small solar panel on the outdoor unit to significantly reduce the overall climate impact."[145]

Among the more cost-effective technologies, Lalit (2020) notes that three are especially promising. (i) The first uses a "a multi split method … to connect three indoor units" that optimizes refrigerant flow depending on cooling load and uses control technology to modulate capacity. The multi-unit, regulated approach combined with evaporative cooling technology. (ii) A second approach "integrates an electro-osmotic membrane dehumidifier with a water-based direct evaporative cooling system to achieve air conditioning without using any refrigerant." (iii) A third approach reduces energy consumption by separating the temperature and humidity control processes. It uses a new desiccant to remove water vapor from the air and the drier air then becomes easier to cool.[146]

District cooling, which aggregates the demand from a number of residential and commercial buildings, is another way of increasing efficiency and is being rolled out in the Gulf Cooperation Council (GCC) countries. Innovative architectural designs that incorporate passive cooling mechanisms in buildings also reduce energy consumption.[147] Such designs transfer heat from inside a building to exterior heat sinks. Where the air is dry, adding moisture directly or through passive downdraft evaporative cooling, which pulls in air through hoods on the roofs of buildings and draws the air across a pool of water or a fountain, is another cost-effective technique used in the Middle East and Northern India. Retrofitting these and other technologies into existing structures will be costly and there will be additional costs incurred in designing, insulating, and installing cooling equipment in structures yet to be built.

A related area of research is renewable energy technologies. Electrification of the economy and the greater use of cooling equipment must go hand-in-hand with decreased reliance on fossil fuels, as well as a further substantial decline in the cost of power from renewable sources.[148]

As wind and solar begin to bulk large in the energy picture, the importance of distributed generation,[149] the use of smart grid technology, and utility-scale storage devices will increase.[150] This is a third area of research and innovation complementing the other two that calls for active engagement by developing countries in both advancing the technology and putting it to use. Distributed generation has been around for over a century, but it is now entering a new technological epoch and developing countries should actively participate in pushing the technology frontier and not watch from the sidelines.

Minimizing the exposure to extreme heat in occupations such as farming, manufacturing, and construction will also call for innovation. Some of it will take the form of mechanization and automation tailored for the requirements and resources of developing countries that limit the exposure of workers to high temperatures. 3D printing of houses,[151] factory production of modules[152] that can be assembled on site using mechanized equipment, and other advances will need to be assimilated by countries where construction is still very labor intensive and relies on dated technology. Similarly, the preparation of land for farming, planting harvesting, processing, picking of fruit and vegetables, and myriad other activities that are part of the food value chain can and are being automated in advanced countries. The technology is capital and skill intensive however, it needs to be made more user friendly and its use scaled up to bring down costs. Indian and Chinese firms are doing some of this. Other countries need to step up their own research, development, and innovation so that the technology can evolve and be transferred more rapidly to tropical countries where it will be needed as warming continues.

2.5. Protecting Health

The COVID-19 pandemic has focused attention on the vulnerability of a globalized economy to infectious diseases. Medical experts warn that the incidence of disease outbreaks could increase.[153] In part this will be the result of pathogens that mutate and crossover from animals to humans as population growth encroaches on animal habitats and there is greater exposure to wild species.[154] Ebola fever caused by a virus from the Filoviridae family is one such disease; HIV is another.[155] There are several more and black swans surely to come that we cannot now identify.

Climate change will extend the range of disease-carrying vectors such as the *Aedes aegypti* and *Anopheles* mosquitos, which spread malaria, yellow fever, Zika, encephalitis, rift valley fever, and dengue fever, among others. For example, the incidence of malaria is correlated with higher temperatures in Pakistan and those prevailing in Venezuela and Colombia following El Nino events.[156] The range of other disease-transporting insects and pests will also expand.

Warming is also likely to exacerbate heart and respiratory conditions, allergies, and increase the risks of death from heat stroke. Food spoilage is another concern in the absence of secure cold chains and widespread access to affordable refrigeration. Diseases caused by the contamination of food will present the greatest risk to the poor. Outbreaks of food and water-borne diseases are already a problem. Unless the food chain and food storage are made secure, the problem will worsen. Inequality of access to refrigeration will cause more harm than it does at present (Figure 14).

Climatologists warn that the frequency and severity of floods, storms, heat waves, wildfires, and droughts will increase. These will inflict a heavier toll on health than they currently do as more people are now living in coastal areas, on flood plains, in tropical regions, and at the urban-wildland interface[157] and therefore, more exposed damaging events.

Figure 14: Health risks and impacts

	Exposures affected by climate change	*Health risks*	*Health impacts*	*Confidence rating*
Direct effects	Increased numbers of warm days and nights; Increase in frequency and intensity of heatwaves; Increased fire risk in low rainfall conditions	Excess heat related mortality; Increased incidence of heat exhaustion and heat stroke, particularly for outdoor labourers, athletes, elderly; Exacerbated circulatory, cardio-vascular, respiratory, and kidney diseases; Increased premature mortality related to ozone, and air pollution produced by fires, particularly during heat waves	Greater risk of injury, disease, and death due to more intense heat waves and fires	Very high
	Decreased numbers of cold days and nights	Lower cold-related mortality, reduced cardiovascular, and respiratory disease, particularly for the elderly in cold and temperate climates	Modest improvements in cold-related mortality and morbidity	Low
Effects mediated through natural systems	Higher temperatures and humidity, changing and increasingly variable precipitation, higher sea surface and freshwater temperatures	Accelerated microbial growth, survival, persistence, transmission, virulence of pathogens; Shifting geographic and seasonal distributions of e.g. cholera, schistosomiasis, and harmful algal blooms; Lack of water for hygiene; Flood damage to water and sanitation infrastructure, and contamination of water sources through overflow	Increased risks of food- and water-borne diseases	Very high
	Higher temperatures and humidity, changing and increasingly variable precipitation	Accelerated parasite replication and increased biting rates; Prolonged transmission seasons; Re-emergence of formerly prevalent diseases; Changing distribution and abundance of disease vectors; Reduced effectiveness of vector control interventions	Increased risks of vector-borne diseases	Medium
Effects heavily mediated by human systems	Higher temperatures and changes in precipitation	Lower food production in tropics; Lower access to food due to reduced supply and higher prices; Combined effects of undernutrition and infectious diseases; Chronic effects of stunting and wasting in children	Increased risk of under-nutrition resulting from diminished food production in poor regions	High
	Higher temperatures and humidity	Outdoor and unprotected workers obliged to work in physiologically unsafe conditions, or to lose income or livelihood opportunities	Consequences for health of lost work capacity and reduced labour productivity in vulnerable populations	High
Combined effect	Overall climate change	Combination and interactions of risks above	Negative health effects will outweigh positive effects worldwide	High

Source: WHO (2016).

By magnifying these risks, climate change will require increased spending on the hardening of existing infrastructure and the building of additional infrastructures to provide the needed protection. There will be a complemental need to expand public health and other emergency services, which are inadequate in most developing countries. With warming, strengthening infrastructures and services will become a higher priority with fiscal implications for governments.

2.6. Augmenting State Capabilities to Cope with Shocks

State capabilities and governance in many if not most developing countries are barely adequate and there is scant evidence of an improving trend.

The list of fragile states is long and a number of states in some of the most environmentally challenged parts of the world are on the brink of failure.[158] These countries have youthful and growing populations, their economic performance is marginal, domestic resource mobilization is inadequate, and few are demonstrating the capacity to plan and implement a growth strategy that is likely to be sustainable in the face of climate change As Andrews, Pritchett, and Woolcock (2017) note, "In most developing countries, the quality of institutions presiding over such tasks is flatlining or actively declining."

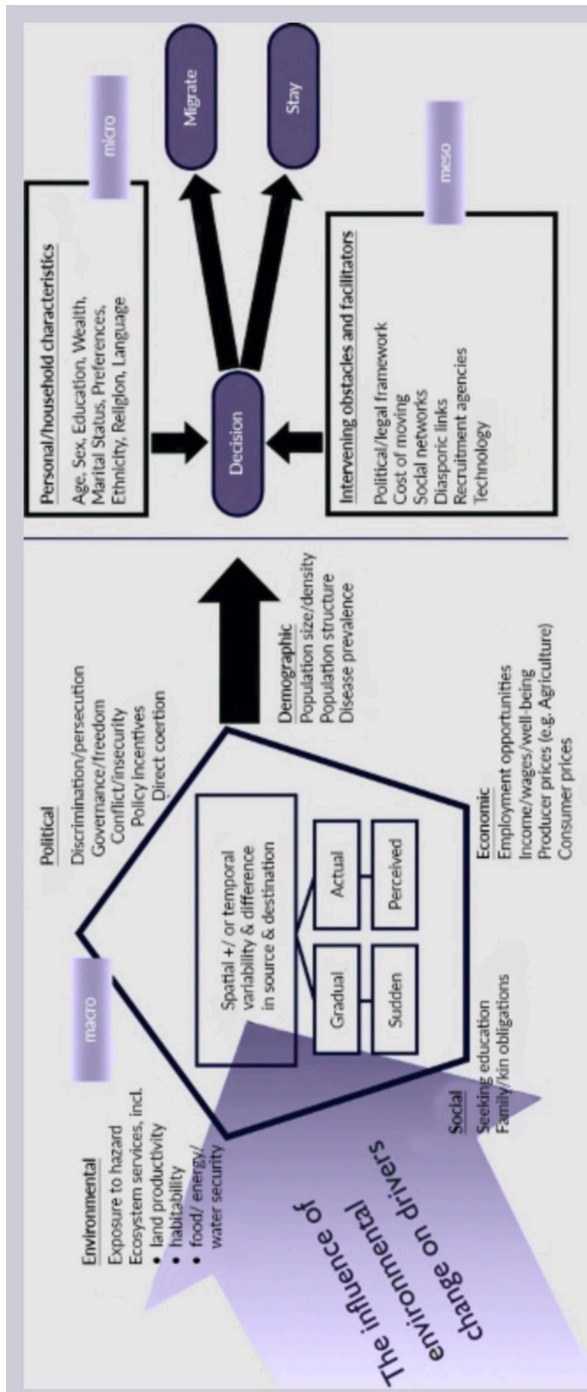
As countries recover from the scarring inflicted by the COVID-19 pandemic, they have an opportunity to chart a development path that is less dependent on carbon and material resources. The challenge will be to identify a path for countries that is viable, an improvement over the pre-pandemic course, is within their governance capabilities, and can be accommodated in a (temporarily) reduced resource envelope.

Private initiatives, guided by market signals and the profit motive, can lead to investments, technological change, and innovation that reduce GHG emissions and make economies more resilient.[159] But the mitigation and adaptation induced by market forces does not suffice. Markets fail to price the externalities caused by GHGs,[160] hence governments need to take the lead to price carbon and to invest in technology and infrastructure. The private sector will either not invest or will ignore social benefits and invest too little.[161] There are signs that major corporations, financial institutions, and insurers are waking up and beginning to take steps to decarbonize. However, less than 3,000 companies have been willing to disclose their carbon footprints, only 1,600 (mostly in advanced economies) have announced carbon reduction targets, and just 1,000 have actually achieved measurable progress. The task is relatively painless for financial firms, much harder for those delivering transport services.[162]

The threat posed by climate change has magnified the demands on the state. Drought, floods, heatwaves, and hurricanes cause damage and disrupt economic and social activities. The effects can be long lasting. Middle- and upper middle-income countries can—up to a point—absorb the losses and rebound; but lower middle- and low-income countries with populations living close to subsistence levels can suffer a breakdown of a precarious economic equilibrium and the social order. Weak or flailing states[163] with limited organizational capabilities, fiscal headroom, or capacity to borrow from international sources are the ones at greatest risk. A succession of shocks impacting countries with weak institutions, where governments enjoy little trust and societies are weakened by the fracturing of social consensus, could easily result in existential crises that overwhelm both governments and international agencies. Such crises could in turn triggering mass migrations and localized conflicts that spiral into regional ones.

The Syrian crisis and the movement of people from Central America to the United States and from Northern Africa to the EU provide a foretaste of worse to come if climate change remains on its current trajectory and governments do not take preemptive action against future shocks. The World Bank estimates that by 2050 the number of climate migrants will increase by 143 million.[164] The extent of disruption and how much movement of people does in fact occur will be determined by many factors as shown in Figure 15.

Figure 15: Climate and environment related drivers of migration



Source: de Sherbinin (2020).

Suffice to say, government capability to mobilize resources, and to proactively work with the private sector to curb GHGs and enhance climate resilience, will determine how effectively shocks are managed and scarring minimized.

The key message for developing countries (and not just developing ones) is that a redoubling of efforts to cap global warming is critical. A number of actions spelled out below that have been debated for years now need to be implemented quickly and forcefully. A second message is that in order to marshal the resources needed to contain climate change and to prepare for shocks to come, developing countries must emphasize economic growth more than ever and boost revenue mobilization. A third message is that countries need to take full advantage of technologies now available and invest in R&D so as to find even more efficacious technologies. The fourth message for developing countries, multilateral donors, and UN agencies is that whatever progress has been registered so far and whatever gains have been secured, these will be degraded by inevitable climatic events and consequential economic implications. Therefore, these climate change perils should be factored into current planning and decision making.

3. What EMDEs Must Do

The 26th session of the COP will take place in November 2021. Expectations are running high with the United States playing an active role along with China. The outcome of COP 25 was disappointing with many agenda items left unresolved. This time around, EMDEs must work with high-income nations to ensure that an opportunity is not squandered. The clock is ticking and rapid progress during this decade is crucial.

3.1. Mitigating Measures

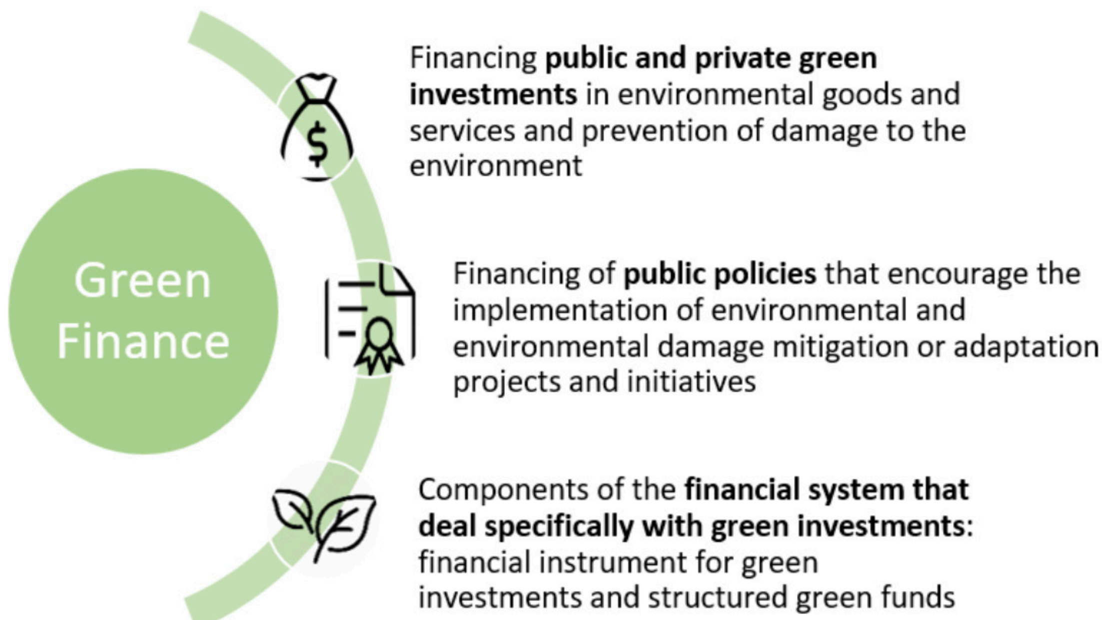
Mitigation and adaptation are the two watchwords for developing countries (Nordhaus 2013).[165] Mitigation of the release of GHGs[166] calls for action calls for action on five fronts.

The first mitigation front is a steady electrification of economies, with a rapid increase in the share of power that is sourced from renewables.[167] Now that solar and wind power are more competitive, it is easier to switch from fossil fuels (particularly coal) without incurring a sizable cost penalty.[168] Countries have made a start including coal rich ones such as India, and the IEA projects that 95 percent of the net increase in electricity generating capacity through 2025 will be from renewables. Much of this will be in the OECD countries and China.[169] Greater participation by EMDEs is highly desirable and financial institutions can accelerate the process by scaling back lending for fossil-fueled generating capacity and offering better terms for the construction of renewable power plants.

As UN Special Envoy for Climate Action and Finance Mark Carney (2021) notes, people are voting with their money and demanding that banks, pension funds, and asset managers use their investments to expedite the transition to net zero.[170] "The stakes are high, but the commitment of all actors in the financial system to act [and grasp the commercial opportunity presented by low carbon technologies] will help avoid a climate driven 'Minsky moment' [that is] a sudden collapse in asset prices [and the bankruptcy of firms that do not adapt]."[171] Discussions by G20 representatives have highlighted the need to involve a multitude of actors from across the financial system including IFIs, banks, institutional investors, rating agencies, and stock exchanges, as well as central banks and financial regulatory authorities. Central banks and regulatory authorities in countries such as India, South Africa, and Indonesia have already introduced roadmaps to steer lending towards renewables, as well as disclosure requirements and lending guidelines to promote green finance.[172] The Central Banks and Supervisory Network for Greening the Financial System now includes 90 members up from just seven when it was created in 2017. Central banks are also considering whether to require banks to set aside more capital for loans to fossil fuel-based companies and less for those that utilize power from renewable sources, thereby exerting direct influence on the allocation of credit.[173]

A variety of instruments can speed the transition to renewables in particular, the use of green finance from a variety of Funds, financial and insurance products, which integrate ESG into investment decisions– Figure 16.[174] Green bonds (a fixed income asset class first issued by the EIB in 2007 that began maturing in 2013) and loans although still in their infancy are gaining traction and likely to be among the principal sources of finance for companies seeking ecological sustainability.[175] Other instruments that play a role are feed-in tariffs, and auctions complemented by investment in smart transmission and distribution systems.

Figure 16: Green financing



Source: https://www.greengrowthknowledge.org/page/explore-green-finance.

The second front of the mitigation effort is the pressure of market forces. Carbon pricing and emission trading platforms can bring market forces to bear on the use of fossil fuels and promote conservation through multiple channels including urban design and the use of telecommuting, more efficient use of energy, and electrification. Carbon offsets, mainly by companies in developed countries, could channel resources to developing countries that contribute to reforestation, the expansion of renewable generating capacity, and to low-carbon techniques of production.[176] However, voluntary offsetting schemes have had a limited impact on emissions if any. In many instances, they have enabled companies to defer needed investments and actions to cut emissions. Such 'greenwashing' and 'brown-spinning'[177] will continue so long as investors do not hold companies to account.

A third front is financial and tax incentives, which are among the instruments available to the state. Public and private investment in R&D can quicken the pace of innovation and extension services can facilitate diffusion.[178] Regulations and penalties on emissions exceeding a certain level—when backed with effective monitoring, testing, and enforcement—have their place alongside market mechanisms and incentives. Standards for transport and industrial equipment and for infrastructures, when combined with the others, can be potent medicine.[179]

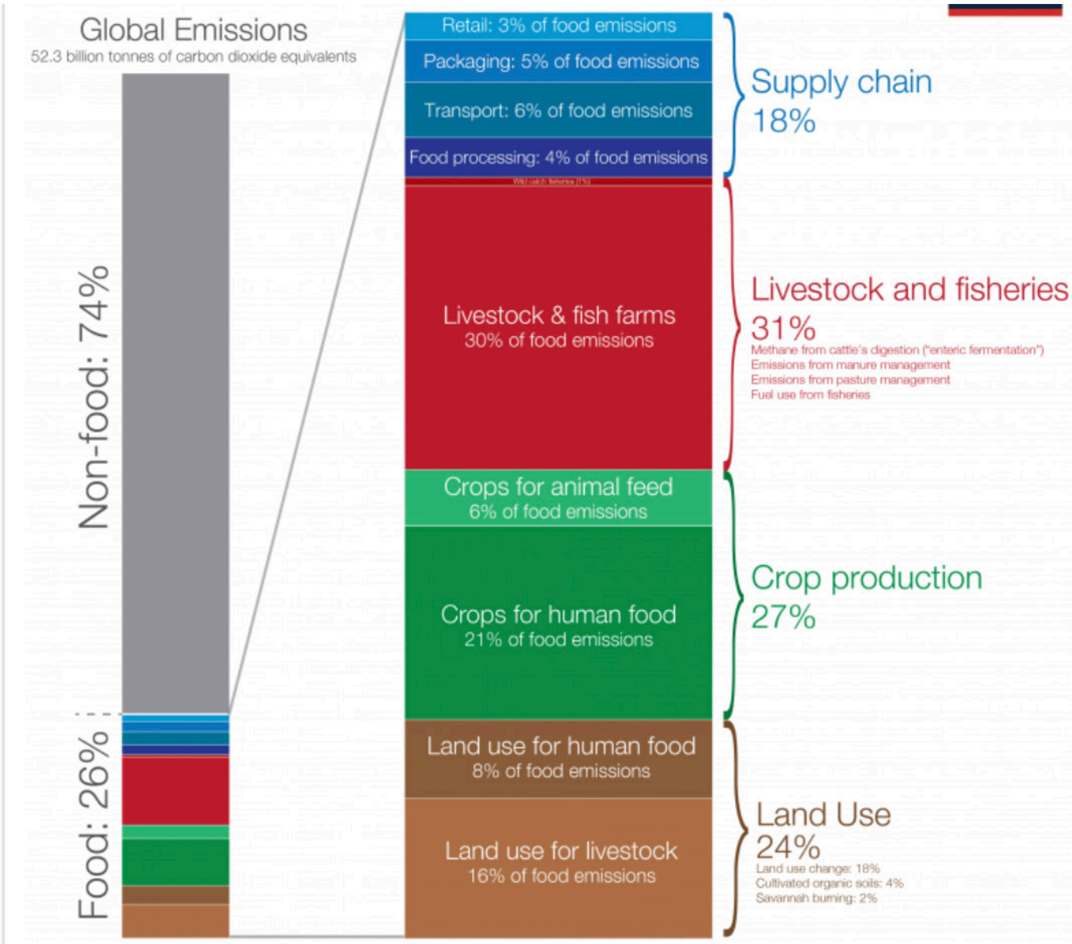
The fourth mitigation front is technology adoption and advancement. A number of available options are noted above and others are appearing daily. But adoption is not keeping pace. The major emitters of GHGs—transport, industries, and buildings—must be required to make use of the cost-effective, efficiency enhancing, and emission reducing innovations that are on offer. The scope for reducing pollutants and gases from some of the leading emitters is large.

For industries such as steel and cement, decarbonization will call for major technological shifts. Each ton of steel results in the release of 1.25 tons of CO_2 and the industry as a whole is responsible for about 8 percent of CO_2 emissions. Steel producers are testing a variety of technologies including the use of hydrogen and carbon capture to cut emissions.[180] Unit costs are still high, but progress is being made. Instead of building basic oxygen or integrated furnaces, greenfield plants in developing countries can use electric arc furnaces with scrap and green hydrogen and drastically reduce emissions.[181] Cement, chemical industries, and producers of aluminum are some of the others needing to transition to low-emission technologies.

The 2014 IPCC report presents some of the options not only for reducing CO_2 but also emissions of nitrous oxide and refrigerants.[182] To balance the voltage on the grid, fossil- (or nuclear) powered capacity will still be needed in order to compensate for the fluctuation in power from intermittent sources—until such time as adequate grid level storage systems become available. The penalty in terms of carbon emissions can be minimized by using gas-powered turbines instead of coal fired ones. However, as battery storage technology improves and becomes more cost effective, the need for back-up gas fired generating capacity would diminish.[183]

A fifth mitigation front is agriculture practices, of particular relevance to a subset of EMDEs. Agriculture accounts for a quarter of GHGs with crop production and land use responsible for one half of the total (Figure 17). Low-tillage, precision agriculture technology using variable rate application of fertilizer can substantially lower GHG emissions. These practices conserve carbon in the soil, are sparing in the use of inputs, and limit the release of nitrous oxide[184] by carefully metering the application of fertilizer.[185] Furthermore, deforestation for the purposes of pastoral farming and crop production is another major source of emissions from a few countries. In Brazil and Indonesia, for example, deforestation is adding millions of tons of carbon to the atmosphere.

Figure 17: Carbon emissions from agriculture



Source: Ritchie (2019).

Precision agriculture technology is being mainstreamed in OECD countries but making slow headway in developing ones. Large commercial farms have adopted some of the practices, but the vast majority of smaller cultivators fall far short. Public agencies, private buyers and suppliers, and the diffusion of digital technologies are receiving attention from farmers. However, more can and should be done, given the pressure that warming is already exerting on agriculture systems worldwide. Risk-averse, often semi-literate small farmers are reluctant to switch from proven techniques, are constrained by indebtedness, have limited access to credit and supplies of inputs, and are individually unable to invest in or utilize complex equipment.

Slowing if not halting deforestation presents a tough challenge for governments eager to expand export-generating cultivated acreage, accommodate a growing population, and fend off powerful corporate interests as in Brazil.[186] Pressure from the international community and buyers has failed to halt the retreat of the remaining tropical forests. Although governments could slow the process with strict regulation and enforcement, they have been either unwilling or powerless to do so.[187]

Climate change can be controlled. The decade of the 2020s might see an intensification of efforts to produce National Plans (Korea, which generates 40 percent of its electricity using coal, is promising bold measures[188]). Other actions that may ramp up are the collecting of accurate data on emissions and credible pledges to curtail them,[189] the crafting of techniques of enforcement, and the trading of carbon emissions at prices high enough to produce results.[190]

Carbon pricing suitably designed,[191] and political opposition permitting, could begin gaining traction and accelerate the shift to non-fossil sources of power and to electric vehicles. The corporate sector is showing greater awareness of the seriousness of the shocks climate change will inflict and also of the opportunities, which could be tapped through decarbonization. Research on green technologies could benefit from an infusion of public and corporate funding. After due negotiation, there may be a readiness on the part of developed economies to accede to the demands of EMDEs for financing and technology transfers. Breakthroughs in (for example) power storage systems, carbon capture and sequestration, techniques of cooling, in the production and use of green hydrogen, and the spread of precision farming, would make it easier to realize the emission pledges. Although battery storage has a very small share of storage capacity (1 percent in the United States), as costs decline and technology advances, the contribution of batteries is expected to rise sharply.[192]

3.2. COP 26 Objectives

The ongoing negotiations among countries are more likely to produce a viable outcome if there is an international framework for cooperation. As Nick Stern (2015: 251) writes: "An international climate framework that can cope with the uncertainties in climate outcomes and impacts, and at the same time foster a shared understanding not only of the risks from failing to collaborate nationally and internationally, but also of the potential for dynamic learning and for Schumpeterian waves of discovery and innovation."

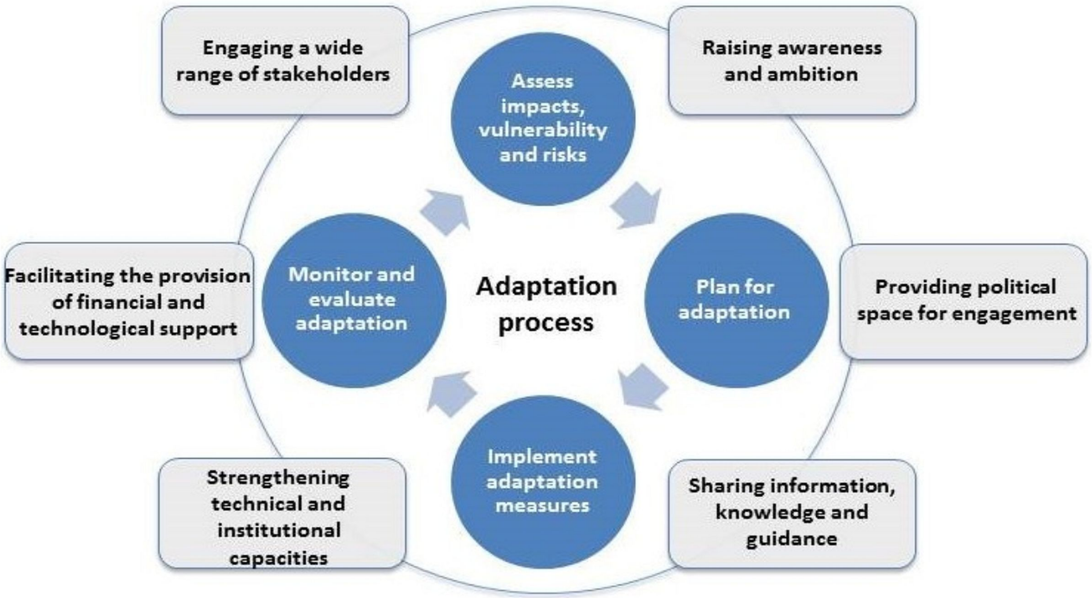
At the national level, success at mitigation and adaptation will hinge on government resolve and capabilities. But many other public and private actors have essential roles as well, including "the active and sustained engagement of stakeholders including national, regional, multilateral and international organizations, the public and private sectors, civil society and other relevant stakeholders, as well as effective management of knowledge"[193] (see Figure 18).

Assuming that the majority of governments in EMDEs do seek to green the recovery from the COVID-19 pandemic and set their sights on capping the increase in mean global temperature to 1.5°C, they will need to:

- substantially improve the capability to plan, regulate and enforce first a green recovery and then a greening of growth and also the geography of development;
- mobilize and efficiently allocate capital to build the low emission production capacity and the needed infrastructures;
- increase their investment in the human and knowledge capital required to assimilate the available technologies and create new and more effective ones; and
- use every means at their disposal to enhance the awareness of the urgent need to halt climate change.

The challenge as Martin Sandbu (2021) rightly observes is gargantuan. But if countries can arrive at an agreement that is as effective in capping GHG emissions as the Montreal Protocol was in reversing ozone depletion, the "result need not feel like a revolution" because we have the technologies needed to make the transition to a zero net carbon emission world at relatively low cost. "Unlike in a war, victory in the climate fight would amount to our day-to-day living going on much as it did before…. Failure could upend catastrophically the normality most people aspire to."

Figure 18: How to manage and control climate change



Source: https://unfccc.int/topics/adaptation-and-resilience/the-big-picture/what-do-adaptation-to-climate-change-and-climate-resilience-mean.

3.3. Responding to Climate Change

While all countries have experienced an uptick in their vulnerability to climate change and many have suffered from severe weather events, 10 countries have taken the greatest battering (Figure 19). Among the most exposed going forward are countries like Haiti, the Philippines, and Pakistan. The latter has endured repeated floods and droughts, water scarcity is a problem in some areas, and heat waves have become more frequent. It is clear that programs of action are required by all countries, particularly those destined to be most affected. Waiting until disaster strikes is never a smart policy, even if the full deleterious effects will become apparent a decade hence.

Suggested actions for Pakistan can serve as a template for the range of policy measures required for climate change mitigation:

1. In order to conserve water resources and efficiently utilize dwindling supplies, Pakistan must use pricing policies, regulatory measures, standard setting, technological advances, and public education campaigns to control water use and augment supply through desalination, recycling, and increased storage. This will also be critical for many countries in the Middle East.

Figure 19: Long-term climate risk index: Countries most affected by climate change during 2000–2019

CRI 2000-2019 (1999-2018)	Country	CRI score	Fatalities	Fatalities per 100 000 inhabitants	Losses in million US$ PPP	Losses per unit GDP in %	Number of events (2000–2019)
1 (1)	Puerto Rico	7.17	149.85	4.12	4 149.98	3.66	24
2 (2)	Myanmar	10.00	7 056.45	14.35	1 512.11	0.80	57
3 (3)	Haiti	13.67	274.05	2.78	392.54	2.30	80
4 (4)	Philippines	18.17	859.35	0.93	3 179.12	0.54	317
5 (14)	Mozambique	25.83	125.40	0.52	303.03	1.33	57
6 (20)	The Bahamas	27.67	5.35	1.56	426.88	3.81	13
7 (7)	Bangladesh	28.33	572.50	0.38	1 860.04	0.41	185
8 (5)	Pakistan	29.00	502.45	0.30	3 771.91	0.52	173
9 (8)	Thailand	29.83	137.75	0.21	7 719.15	0.82	146
10 (9)	Nepal	31.33	217.15	0.82	233.06	0.39	191

Source: Eckstein, Künzel, and Schäfer (2021).

2. Define and begin a phased implementation of a managed retreat of urban habitation and agriculture from coastal locations and deltaic areas as sea levels rise rendering coastal areas virtually uninhabitable (Hasnoot et al 2021). Over time, highly exposed, low-lying cities in Pakistan, Bangladesh (as many as 13.3 million people would need to relocated from the coastal areas by 2050), and the Philippines will have to be abandoned as the cost of building defenses becomes prohibitive (Khan et al 2021). In some cases, a preemptive downsizing of cities and phased withdrawal might be a cost-effective strategy. The frequency of severe flooding might make it necessary to abandon some developments in floodplains as well.

3. Plan for the relocation of populations from inland areas as well. Heat, drought, desiccation, and desertification will take their toll on farming and on cities across Pakistan,[194] Northern India, and parts of North Africa and SSA. Pastoral farming and cultivation might cease in some areas and urban habitation could begin to shrink under the press of high temperatures, water shortages and sandstorms. Populations may need to concentrate in the remaining parts of a country that are still habitable and can support agricultural activity. The GCC countries, Iran, and Pakistan are recording summer temperatures close to or over 50°C, soil erosion is worsening, and aridity is on the rise.

4. Urbanization will increase because the land available for cultivation could shrink and farming will become less labor intensive. Moreover, the geography of urbanization could change. In some countries the change could be radical and would require a corresponding adjustment, building, and weather proofing of the supporting transport, energy, and other infrastructures. For these reasons, increasing the resilience of the food chains by harnessing technologies and investing in infrastructure would lessen the risk of shortages.

5. Warming will affect air quality and as noted above increase the spread of pathogens. Countries will need to strengthen their defenses by more stringently controlling the release of pollutants but also by ensuring that public health facilities are not neglected. The COVID-19 pandemic has served as a wake-up call by revealing the vulnerability of populations and the inadequacy of public health infrastructure.

Country-specific climate action plans are an indispensable first step in responding to the evolving crisis (as suggested in Figure 20).

A gradual increase in temperature and then a flattening out at 1.5°C or even 2°C might permit adaptation. An increase that is compressed into a decade would cause great disruption and suffering. Assuming that mitigation is successful, a world that is warmer and subject to weather extremes and rising sea levels will be forced to adapt. Small island economies are among the ones with the fewest options. To survive they will need to take drastic measures.

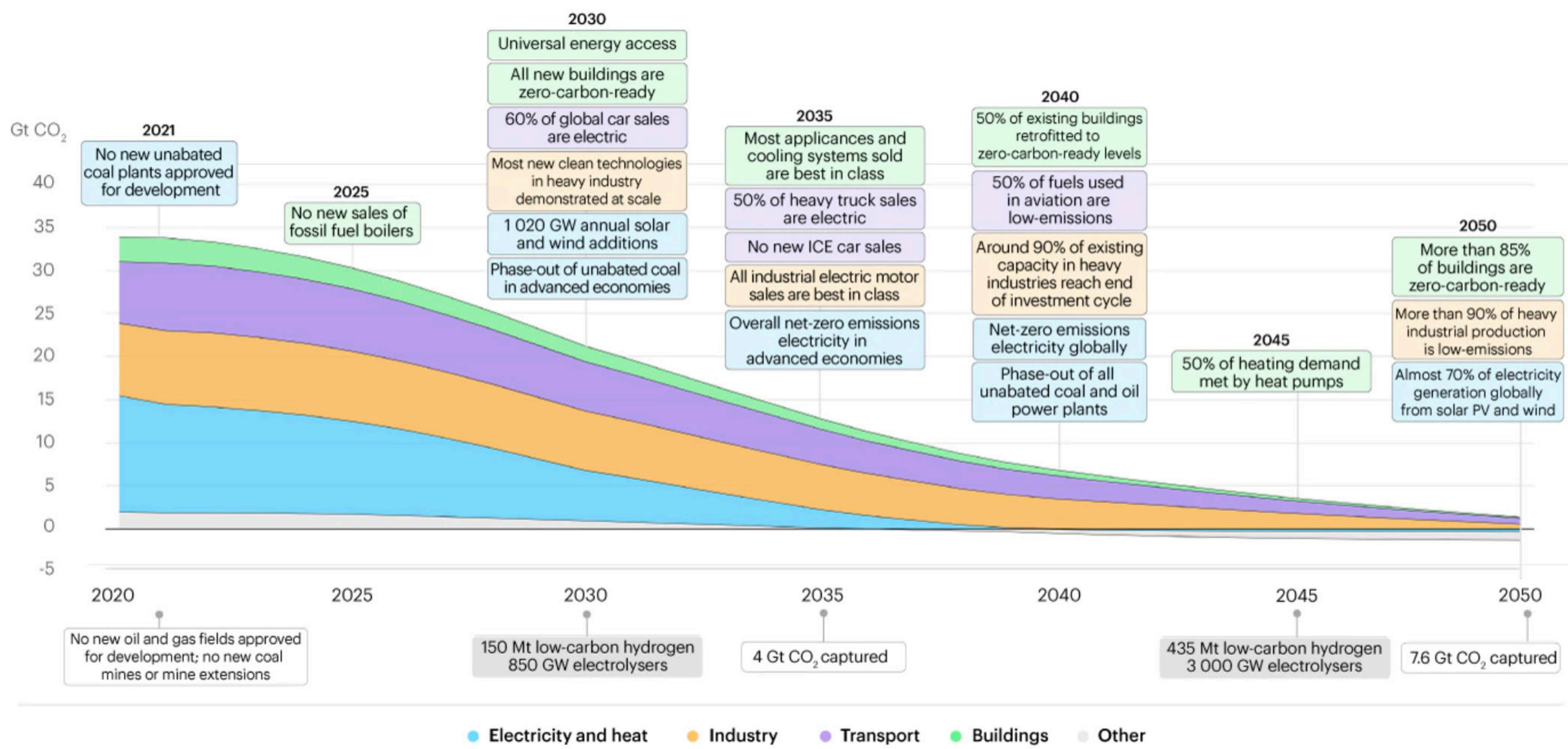
While development assistance agencies are emphasizing the need for building resilience, countries themselves have been slow to respond due to understandable financing constraints. Worrying about tomorrow is less likely when confronted with the urgency of today's economic and social problems. There is vague talk of win-win solutions and smart investments, but insufficient action in most countries. In the same way that a financial crisis can set back development prospects for a number of years, a failure of the most vulnerable countries to address some of the urgent priorities of climate change may ensure that their economic outlook will deteriorate.

4. The Way Forward

While the larger climate challenge is facing the global economy, it is important that countries take the forecasts seriously in the context of their own development circumstances. In the same way that the IMF looks at Debt Sustainability Analysis to gauge the likely impact of policy changes on countries financial capacities, development institutions need to do likewise with respect to climate change impacts. Forecasts and models are always suspect with respect to timing and severity of events. Nevertheless, advances in technology make it possible to somewhat mitigate some of the expected impacts. These kinds of investments require financing, but they also need to be preceded by policy analysis and a shared credible commitment to begin necessary investments early. Growth projections that do not include the likelihood of either catastrophic economic losses or the probability of sustained longer-term economic dislocations are doing all a disservice.[195]

Unfortunately, country planners, already overwhelmed by economic, social, and governance challenges, will need to make this element central to their deliberations and planning efforts. As Funke and Klenert (2020) rightly observe, policy procrastination can be tragic. The main policy message that emerges is that the effects of climate change on economic growth prospects cannot be an afterthought or an annex to a report on development outlooks. It will increasingly need to be central to all projections, since even a more favorable global outlook will entail major dislocations for many countries. At the same time, the effects of climate change will create new challenges for those concerned with poverty reduction, inequality in the population, migration pressures, and societal stability.

Figure 20: Milestones for long-term targets



Source: IEA (2021).

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Endnotes

[1] McSweeney (2020); Pearce (2019); Lenton et al. (2019).
[2] Letzter (2021).
[3] There is general agreement that absent aggressive curtailment, the safe worldwide temperature threshold would be crossed within a couple of decades (Levin 2018; MCC n.d.; Hausfather (2018).
[4] There is a 1 in 20 chance that the 2.2 trillion tons of CO_2 in the atmosphere could give rise to an existential crisis (Scientific American 2017). Scientists R. Pachauri, J. Hansen, and others have been warning since 2005 that the window of opportunity is closing (Sawin 2007).
[5] Scientific American (2013). Even if the poorest 52 countries achieve high rates of growth, their share of emissions would most likely be less than 10 percent (Baker and Mitchell 2020).
[6] NOAA (2021).
[7] For example, the likelihood of heatwaves will increase in North and Northeast China as average temperatures rise. Also, the warm spell duration will increase in Southern China (Sun et al. 2019).
[8] "Between 2000 and 2019, over 475,000 people lost their lives worldwide and losses of US$2.56 trillion (in PPP) were incurred as a direct result of more than 11,000 extreme weather events… By 2030 it is projected that these costs will amount to between US$140 billion and US$300 billion annually and by 2050 to between US$280 billion and US$500 billion" (Eckstein, Künzel, and Schäfer 2021).
[9] Wallace-Wells (2020).
[10] Cho (2018); Flavelle (2019); Ray et al. (2019); https://www.ipcc.ch/site/assets/uploads/2019/08/2f.-Chapter-5_FINAL.pdf.
[11] Garthwaite (2019); https://www.watercalculator.org/footprint/climate-change-water-resources/.
[12] Between 2030 and 2050, the WHO projects that annual mortality will increase by 250,000. https://www.who.int/news-room/fact-sheets/detail/climate-change-and-health
[13] Kjellstrom et al. (2009).
[14] Goodman et al. (2019); At temperatures in excess of 26°C, students' cognitive performance in mathematics tends to decline (Zivin et al. 2015, 2018).
[15] Over 140 million people could be displaced and forced to migrate within countries and across borders (World Bank 2018).
[16] https://nca2014.globalchange.gov/highlights/report-findings/infrastructure; Low (2019); TRB (2008).
[17] Mach et al. (2019); Burke et al (2014); Sneed (2019); https://int.nyt.com/data/documenthelper/1103-rod-schoonover-testimony/9ea6b07179b17035421f/optimized/full.pdf#page=1.
[18] Plante and Anderson (2017); UN Climate Change News (2019). The incidence of crime increases once temperatures rise above a certain threshold. In Los Angeles the threshold is 85°F (Heilmann and Kahn 2019).
[19] The Indonesian government is being forced to relocate the capital to East Kalimantan because of the threat from rising sea levels and storms (Lin, McDermott, and Michaels 2021; Eliraz 2020).
[20] Nicholls et al. (2007).
[21] Reliable climate records are available for about 150 years (Hirst 2020; Davies 2020).
[22] Shan et al. (2021) maintain that forceful policy action will be required to build back greener and to extend the dip in emissions during 2020 into the future. See also Tollefson (2021) and Vaughan (2020).
[23] https://www.co2.earth/daily-co2.
[24] IPCC (2018). *Nature Climate Change* presents some of the latest research on warming and its consequences (https://www.nature.com/nclimate/). See also Jeffrey-Wilensky (2019); Cappucci and Samenow (2021).
[25] Frölicher et al. (2018); Laufkötter, Zscheischler, and Frölicher (2020).
[26] Since the beginning of the industrial era, the oceans have absorbed over 525 billion tons of CO_2 from the atmosphere. https://ocean.si.edu/ocean-life/invertebrates/ocean-acidification; Nordhaus (2013: 113–115). In addition, the increase in the number of marine heatwaves threatens vital ocean food chains (Viglione 2021).

[27] https://climate.nasa.gov/evidence/; Blunden (2020).
[28] Eckstein, Künzel, and Schäfer (2021).
[29] Gopalakrishnan et al. (2019); https://19january2017snapshot.epa.gov/climate-impacts/climate-impacts-coastal-areas_.html
[30] Fawthrop (2019); Lovgren (2020); Chellaney (2019). The ice sheets (e.g. Purugangri) and permafrost in the Tibetan region are the third largest repository of fresh water after the Antarctic and the Arctic regions. It is a region that is warming three times faster than the global average (Vince 2019; Song et al. 2019; Palmo 2019; Wester et al. 2019; Krishnan et al. 2019).
[31] ADB (2009, 2017); Burke and Stott (2017); Chaudhri (2018); NIC (2010).
[32] Barghouti (2021).
[33] https://climateactiontracker.org/global/temperatures/; Nuccitelli (2020). The IPCC lists a number of carbon drawdown technologies (CDR) including bioenergy with carbon capture and sequestration (BECCS) and other means by which CO2 concentration and ocean acidification could be stabilized. It does not favor solar radiation modification (SRM) geoengineering as yet (https://climatenexus.org/international/ipcc/ipcc-1-5c-report-planet-nearing-tipping-point/).
[34] Limiting the increase in average temperature to 1.5°C is what scientists believe is urgently needed. See Roberts (2018); Buis (2019); Grant and Naish (2019); https://interactive.carbonbrief.org/impacts-climate-change-one-point-five-degrees-two-degrees/?utm_source=web&utm_campaign=Redirect; https://www.climateemergencyinstitute.com/2c.html; Schleussner et al. 2016.
[35] Warming sea temperatures will slow the decay of tropical cyclones once they hit landfall. Recent research suggests that their intensity persists longer than in the past (Chavas and Chen 2020).
[36] This is because some GHGs will remain in the atmosphere for thousands of years (Hausfather 2010).
[37] Curbing deforestation would be a major contribution to the cause – by countries such as Brazil and Indonesia.
[38] The IPCC issued its first assessment report in 1990.
[39] https://www.un.org/en/conferences/environment/rio1992.
[40] Nordhaus (2021).
[41] The Copenhagen Accord negotiated in 2009 was never formally adopted.
[42] https://unfccc.int/process-and-meetings/the-paris-agreement/the-paris-agreement/key-aspects-of-the-paris-agreement.
[43] The first is due in 2023. https://www.ipcc.ch/about/history/.
[44] EU leaders are aiming to bring emissions down by 55 percent over the course of the decade.
[45] Macmillan-Fox (2020). Details on how China will achieve this reduction are scanty (García-Herrero and Tagliapietra 2021).
[46] Wallace-Wells (2021).
[47] Scientific American (2017); Restuccia, Puko, and Hua (2021); The White House, Briefing Room (2021).
[48] Were these trend rates to persist, temperatures in 2100 could be 2.9°C higher—about 0.6°C less than projected earlier.
[49] Brazil is demanding upfront payment of US$1 billion from the US and other nations to curb the deforestation of the Amazon (Spring 2021).
[50] PowerTechnology (2020); Reuters (2020).
[51] Stanway (2021); Standaert (2021). Chinese officials are now talking of curtailing such investment through the BRI (Climate Home News 2020). Chinese companies are involved in at least 240 coal projects in 25 of the Belt and Road countries (Hilton 2019).
[52] Tett (2021).
[53] Cornwall (2020). Also see Tollefson (2019).
[54] The need to green the recovery from the pandemic is the message from the likes of A. Guterres and P. Espinosa (WEF 2020).
[55] Copenhagen Accord (UNFCC 2010, page 7).
[56] OECD (2020).
[57] Mitchell et al. (2021).
[58] Weikmans and Roberts (2017).

[59] Net zero emissions targets are vague (Rogelj et al. 2021). Were warming to accelerate, a tightening of targets could become necessary, and this could be conducted most expeditiously if countries were to agree to a regular schedule for revisiting and adjusting the targets.
[60] Water vapor is another greenhouse gas, which is on the rise as the planet warms. "The possible positive and negative feedbacks associated with increased water vapor and cloud formation can cancel one another out and complicate matters. The actual balance between them is an active area of climate science research" (https://www.acs.org/content/acs/en/climatescience/climatesciencenarratives/its-water-vapor-not-the-co2.html). See also https://www.sciencedaily.com/releases/2007/11/071102152636.htm.
[61] Warming equivalent measures make it possible to factor in the effects of different gases and to separate those that remain in the atmosphere for a century or more such as CO_2 and nitrous oxide from methane that causes more warming but its residence in the atmosphere is shorter. With the increased release of methane from fracking, a separate reporting of gases emitted by all parties would make targeting more transparent and also enable climatologists to assess the implications of announced targets for global warming.
[62] This is linked to the nature of the contracts countries enter into.
[63] Hovi et al. (2016).
[64] Nordhaus (2021). The literature on climate clubs is reviewed by Hovi et al. (2016).
[65] Estimating the social cost of carbon (SCC) is fraught with complications and the imposition of an import tariff has its downsides. As Pomerleau (2020) notes, the climate club is no silver bullet, but it could be a step towards a workable arrangement in a world running short of time. See also Wagner et al. (2020).
[66] https://www.ipcc.ch/site/assets/uploads/2018/02/ipcc_wg3_ar5_chapter13.pdf.
[67] One game-theoretic approach to the problem is a matching commitments agreement (see Molina et al. 2020).
[68] Zhang et al. (2017).
[69] Increasing meat consumption, particularly of beef, the production of which is responsible for 41 percent of the livestock-related GHG emissions (14.5 percent of total emissions), will only steepen the warming trend (http://www.fao.org/news/story/en/item/197623/icode/). Between 1961 and 2013, the consumption of poultry and fish rose but that of beef and other meats did not decline (York 2021). Bene et al. (2020) find that the sustainability of food systems is in doubt.
[70] Zhao et al. (2017).
[71] See also IPCC (2019), Chapter 5.
[72] Sultan et al. (2019).
[73] FAO http://www.fao.org/climate-smart-agriculture-sourcebook/production-resources/module-b1-crops/chapter-b1-1/en/; IPCC https://www.ipcc.ch/srccl/chapter/chapter-5/; C3 and C4 indicates the number of carbon atoms in the sugar molecules produced by the photosynthesis. CAM is Crassulacean acid metabolism in which carbon dioxide CO2 is fixed at night. Generally, C3 plants are suited to cool, moist conditions, C4 to hot and dry, and CAM to arid conditions.
[74] The widely cultivated Cavendish variety of bananas (a primary source of calories in many countries) is threatened by a fungicide resistant fungal disease, and pests are reducing yields of other fruits and vegetables. Whether gene editing can come to the rescue remains to be seen. http://www.fao.org/economic/est/est-commodities/bananas/bananafacts/en/#.Xnuj2S2ZOfU; Maxmen (2019).
[75] IPPC (2019), Chapter 5, presents other estimates of crop losses from climate change.
[76] Agnolucci et al. (2020) explain: "Analysis of the impact of a 1°C rise in temperature on the set of 12 crops … highlights a negative impact across the majority of countries growing cassava, cotton, groundnuts, millet, oats, pulses and rye."
[77] "Climate extremes, such as drought, heatwaves, heavy precipitation and more are responsible for 18 to 43 percent of variation in crop yields for maize, spring wheat, rice and soybeans" (Deepak 2019). See also University of New South Wales (2019).
[78] IPCC (2019), Chapter 5.
[79] FAO et al. (2020), "Executive Summary."
[80] Alston et al. (2021).

[81] Pocock (2013); Advantec (2016); Navarro (2012).
[82] "Genetic engineering enables molecular biologists to reshuffle genes in combinations not possible in nature, opening up a vast new source of genetic diversity for crop improvement…" (National Research Council 1984). CRISPR and other more advanced tools such as prime editing have made it easier for plant biologists to do their engineering (Zhang et al. 2018; Xu, Hua, and Lang 2019; Khalid et al. 2019; Stein (2019).
[83] Lowry et al. (2019).
[84] De Schutter and Vanloqueren (2016); Fluck (1992); Smil (2019).
[85] See Brown (2018) and Sciforce (2019) for a discussion of the ongoing agricultural revolution.
[86] FAO Climate Smart Agriculture Sourcebook (http://www.fao.org/climate-smart-agriculture-sourcebook/production-resources/module-b1-crops/chapter-b1-1/en/.)
[87] The Food and Land Use Coalition (2021).
[88] Many manufacturing processes, from food processing to steelmaking to the manufacturing of garments, use vast quantities of water; see https://www.usgs.gov/special-topic/water-science-school/science/industrial-water-use?qt-science_center_objects=0#qt-science_center_objects.
[89] Magill (2014). Earlier snowmelt could affect water availability later in the year; and heavier downpours will lead to runoffs and less usable water resources.
[90] NASA (2018); Garthwaite (2019).
[91] Lindsey and Dahlman (2021); WMO (2020).
[92] IPCC (2018: Chapter 1); Plumer and Popovich (2018).
[93] Jiménez Cisneros (2014).
[94] Kelley et al. (2015); Ash and Obradovich (2020); Selby et al. (2017).
[95] World Bank Group (2016).
[96] Parton (2018, 2018a); Zhao et al. (2015). On the availability of water from the Tibetan region, see Scott et al. (2019).
[97] Garthwaite (2019).
[98] China, which controls the headwaters of all the major rivers, continues to build dams on transnational waterways. Moreover, international law provides few guarantees and there are no transboundary agreements except on the Indus.
[99] Atkins (2020); Aamer and White (2019); Shin (2020); OECD/ADBI/Mekong Institute (2020: Chapter 1); Clark (2014).
[100] Drishti (2019); MTR (2015).
[101] https://earthobservatory.nasa.gov/images/91008/groundwater-gains-in-india; Sayre and Taraz (2019); Jain (2018).
[102] Kandeel (2019); Whitman (2019). Some countries have withdrawal rates greatly exceeding 100 percent (Ritchie and Roser 2017).
[103] Ashraf et al. (2021).
[104] An IMF (2015) report maintained that the "annual infrastructure investment gap in Africa's water sector is estimated to be $22 billion."
[105] World Bank (2016: 44).
[106] Dry cooling is used by some power plants, and it cuts down water consumption by 95 percent, but air cooling is more capital and energy intensive. https://www.eia.gov/todayinenergy/detail.php?id=36773. Other techniques using a hygroscopic desiccant are also in use. https://www.energy.gov/sites/prod/files/2014/01/f7/csp_review_meeting_042313_martin.pdf.
[107] See Copeland and Carter (2017).
[108] According to one projection, by 2050, use of water by agriculture will rise by 19 percent. https://www.globalagriculture.org/report-topics/water.html.
[109] Ritchie Roser (2017); http://www.fao.org/aquastat/en/overview/methodology/water-use.
[110] The technologies in current use are either membrane (reverse osmosis) or thermal based (flash distillation) both are capital and energy intensive (Goh et al. 2019). See also Stopyra (2017).
[111] Bienkowski (2015).
[112] Voutchkov (2017).

[113] Membrane-based osmosis technology is employed alongside ultraviolet, ozone and advanced oxidation-based disinfection, electrodialysis reversal, and thermal evaporation and crystallization (Lovely 2018; https://www.epa.gov/water-innovation-tech/examples-innovation-water-sector). Since 2003, Singapore has used these technologies to treat sewage and produce potable and non-potable quality water (https://globalwaterforum.org/2018/01/15/newater-in-singapore/).
[114] Tetteh et al. (2019).
[115] This became glaringly evident following the spate of wildfires in California (Bayliss and Boomhower 2020).
[116] Kirezci et al. (2020). Lin et al. (2021) state that about 10 percent of the world's population are now living in LECZs.
[117] One alternative to protecting exposed habitat would be to abandon these areas and move to less exposed locations. Ultimately that might be unavoidable, but not in the foreseeable future.
[118] OECD (2018); IDB (2018); Streatfeild (2017).
[119] Some inland cities are equally at risk as they pump out the groundwater. Beijing is sinking as is Mexico City by a foot and half each year (Simon 2017).
[120] ADB (2011).
[121] In many parts of the world these wetlands and mangrove forests have been severely compromised by landfill, aquaculture, infiltration of sea water, and the modification of waterways. If the rise of sea levels accelerates, it could outpace the buildup of wetlands and their efficacy as barriers would be quickly eroded (Popkin 2021). https://coast.noaa.gov/applyit/wetlands/identify.html.
[122] A number of World Heritage Cities are confronting multi-hazard risks, including Hue, Aleppo, Cartagena, and Amsterdam. Bigio et al. (2014) examine the scale of the problem and how these cities could survive.
[123] McKinsey (2020).
[124] Abi-Samra (2013); Goldman (2012).
[125] Baum Hedlund Aristei & Goldman PC (2019); McCarthy, Niall. 2019.
[126] Bhattacharya, Romani, and Stern (2012) estimated that EMDEs were spending less than US$1 trillion per year on infrastructure, and suggested that that amount needed to be doubled, and that of this higher amount about 10-15 percent would be needed to make the infrastructure more climate resilient.
[127] Rozenberg and Fay (2019); Lu (2020).
[128] https://outlook.gihub.org/?utm_source=GIHub+Homepage&utm_medium=Project+tile&utm_campaign=Outlook+GIHub+Tile; Woetzel et al. (2017); UNDP (2018).
[129] Calderon, Cantu, and Chuhan-Pole (2018).
[130] See ESMPA (2019); The Global Climate Partnership Fund is another source.
[131] Barbut (2011).
[132] Burke et al. (2015); Hsiang (2010); Niemala (2002); Somanathan et al. (2018). Work effort erodes once temperatures beginning climbing above 22C (Flouris et al. 2018). This has been established through studies of garment, steel industry and call center workers in India and auto workers in the United States. Somanathan et al. (2018); Niemala et al. (2002); Cachon et al. 2012. If current warming trends persist average global per capita incomes could be 23 percent lower and more unequal by 2100, with the US losing up to 2 billion hours of labor in agriculture and construction. Burke et al. (2015); Diffenbaugh and Burke (2019): U.S. Global Change Research Program (2018: 41); Dennis (2016).
[133] Dell et al. (2012).
[134] Hsiang (2011).
[135] Heal and Park (2013); Dell et al. (2013). See also Burke and Tanatama (2019); ILO 2019; Kahn et al. (2019); Kalibata and Skierka (2021); Raymond, Matthews, and Horton (2020).
[136] Ahima (2020) underscores the severity of the threat to humans at high temperatures. "Extreme deviations from the normal core temperature … can be fatal."
[137] Diffenbaugh and Burke (2019).
[138] Islam and Winkel (2017).
[139] Zivin and Kahn (2016).
[140] Lee (2009).
[141] Lalit (2020).

[142] Brown and Domanski (2014). Other options being explored are described in https://arpa-e.energy.gov/?q=slick-sheet-project/high-efficiency-solid-state-cooling-technologies; https://www.energy.gov/eere/amo/advanced-refrigerant-based-cooling-technologies-information-communications-infrastructure
[143] See Temple (2020): "Air conditioning represents one of the most insidious challenges of climate change, and one of the most difficult technological problems to fix."
[144] Established in 2018.
[145] Lalit (2020).
[146] Lalit (2020).
[147] Passive cooling techniques were widely used in earlier times and need to be revived and improved with the help of computerized design and new materials (Freewan 2019).
[148] Some of the technological advances are briefly described in GlobalData Thematic Research (2020).
[149] https://www.epa.gov/energy/distributed-generation-electricity-and-its-environmental-impacts; https://www.sciencedirect.com/topics/engineering/distributed-power-generation.
[150] Heal (2016). On utility level storage also see Cole and Frazier (2019); Thompson (2019).
[151] Bendix (2019).
[152] Dougherty (2018).
[153] Kurane (2010); Jordan (2019).
[154] There are other risks to consider also. Higher temperatures will could increase the number of dangerous pathogens while at the same time subjecting us to greater stress, reducing recuperative sleep time and thereby weakening our immune systems (Goudarzi 2020).
[155] Parrish et al. (2008).
[156] https://www.ncbi.nlm.nih.gov/books/NBK222258/
[157] Radeloff et al. (2018).
[158] https://fragilestatesindex.org; Broom (2019).
[159] M.E. Kahn (2021).
[160] Stern (2008); V. Thomas (2017); Jaffe, Newell, and Stavins (2004).
[161] Governments also are shortsighted as the horizons of elected officials often do not extend beyond a few years.
[162] Scriven (2020).
[163] Pritchett (2009).
[164] Podesta (2019); Lustgarten (2020).
[165] Nordhaus (2013).
[166] Various geoengineering solutions are proposed but thus far all are unproven and potentially risky. If climate talks fail, eventually geoengineering may have to be tried. See Pearce (2019b).
[167] Electrification can both help check climate change and meet the needs of growing economies for energy. See Lee, Miguel, and Wolfram (2000); Philibert (2019).
[168] Nevertheless, power to stabilize the grid and to provide back-up power if the wind does not blow or cloud cover interferes with power generation by solar farms, will need to be sourced from electricity generated by fossil fuels. Natural gas is the leading, low carbon contender. See below.
[169] IEA (2020).
[170] In June 2020, "109 investors with 11.9 trillion euros of assets under management wrote to European Union leaders urging them to use the bloc's stimulus package to speed up its transition to a "climate neutral" economy" (Carney 2021). See also Abnett (2020).
[171] Carrington (2019); Farand (2020).
[172] G20 Insights (2017).
[173] Clark (2021).
[174] https://unfccc.int/topics/climate-finance/the-big-picture/introduction-to-climate-finance; Yale Insight (2019).
[175] Gilchrist, Yu, and Zhong (2021).
[176] Carney (2021).
[177] Unloading high-emission activities onto hedge funds or others at a discount (Clark 2021; Taraporevala 2021).

[178] Popp (2010).
[179] McCarthy and Yacobucci (2016); Theordor (2016).
[180] McWilliams and Zachmann (2021).
[181] McKinsey & Company (2019).
[182] Fischedick et al. (2014).
[183] Blunt (2021).
[184] Nitrous oxide comprises 6 percent of GHGs emitted annually. It has 300 times the potency of CO_2 in trapping heat and it remains in the atmosphere for 114 years or more (see Chrobak 2021).
[185] Balafoutis et al. (2017); Mazai (2013); Benjamin (2020).
[186] Harris (2021).
[187] Tacconi, Rodrigues, and Maryudi (2019). After years of neglect, Indonesia has begun taking measures to control forest fires and illegal logging and restore peat lands. But the scale of the effort needs to be expanded to cover the entire country (Wijaya, Samadhi, and Juliane 2019).
[188] White (2021).
[189] Firms have resisted carbon labelling and the switching by consumers to low carbon products has done little to advance the cause of decarbonization.
[190] Cap and trade programs are already in place in the EU and California, have been initiated by the United Kingdom, and will shortly be launched by China (Wallace-Wells 2021).
[191] See Klenert and Hepburn (2018); Reeves and Sawhill (2021).
[192] See Blunt (2021); IEA (2021).
[193] https://unfccc.int/topics/adaptation-and-resilience/the-big-picture/what-do-adaptation-to-climate-change-and-climate-resilience-mean.
[194] Jacobabad has recorded temperatures in excess of 50°C (Baker 2019; Pal and Eltahir 2015). In June-July 2021, temperatures in the Pacific Northwest were just short of 50°C, with Lytton in British Columbia registering 49.6°C sparking a wildfire that destroyed the village.
[195] A meta-analysis of published climate models concluded that a delay could result in 40 percent increase in the net present value cost of tackling climate change (Jason, Shadbegian, and Stock 2015).

Mean global temperatures have risen by 1.2°C over the preindustrial average and already there is mounting evidence that the environmental impact is accelerating. Severe weather events have become more frequent, with increasingly destructive wildfires, prolonged droughts, thinning Arctic ice, vanishing glaciers, bleaching coral reefs, shrinking biodiversity, and acidifying oceans. Although IPCC reports and the vast literature on the pace and magnitude of climate change make a compelling case for swift action on several fronts, efforts to control greenhouse gas (GHG) emissions, to mitigate warming and to adapt to ongoing and impending changes in the environment, have made limited headway. Fortunately for the planet, public awareness of the existential threat posed by climate change has risen and has begun to sway the thinking of politicians and captains of industry and finance.

This paper briefly summarizes where climate change is heading, reviews the status of international attempts to limit GHG emissions, and identifies roadblocks to an enduring agreement. Second, the paper examines the economic implications of rising temperatures for EMDEs, and takes a critical look at some of the technological fixes that are surfacing. Third, the paper identifies measures developing countries could pursue in conjunction with others so as to take control of the climate change agenda. It is only by anticipating and planning for the challenges to come that countries will be able to contain the costs and sustain needed rates of growth, while achieving carbon neutrality in a reasonable period of time.

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The Growth Dialogue Institute is an independent entity dedicated to promulgating new ideas and policy analysis on the challenges facing developing countries in their quest for sustainable and equitable economic growth. The GDI highlights views of academics, seasoned development experts, and ex-policymakers. It serves to provide the global community with new ideas and unfettered opinions to help influence and shape the development debate.

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