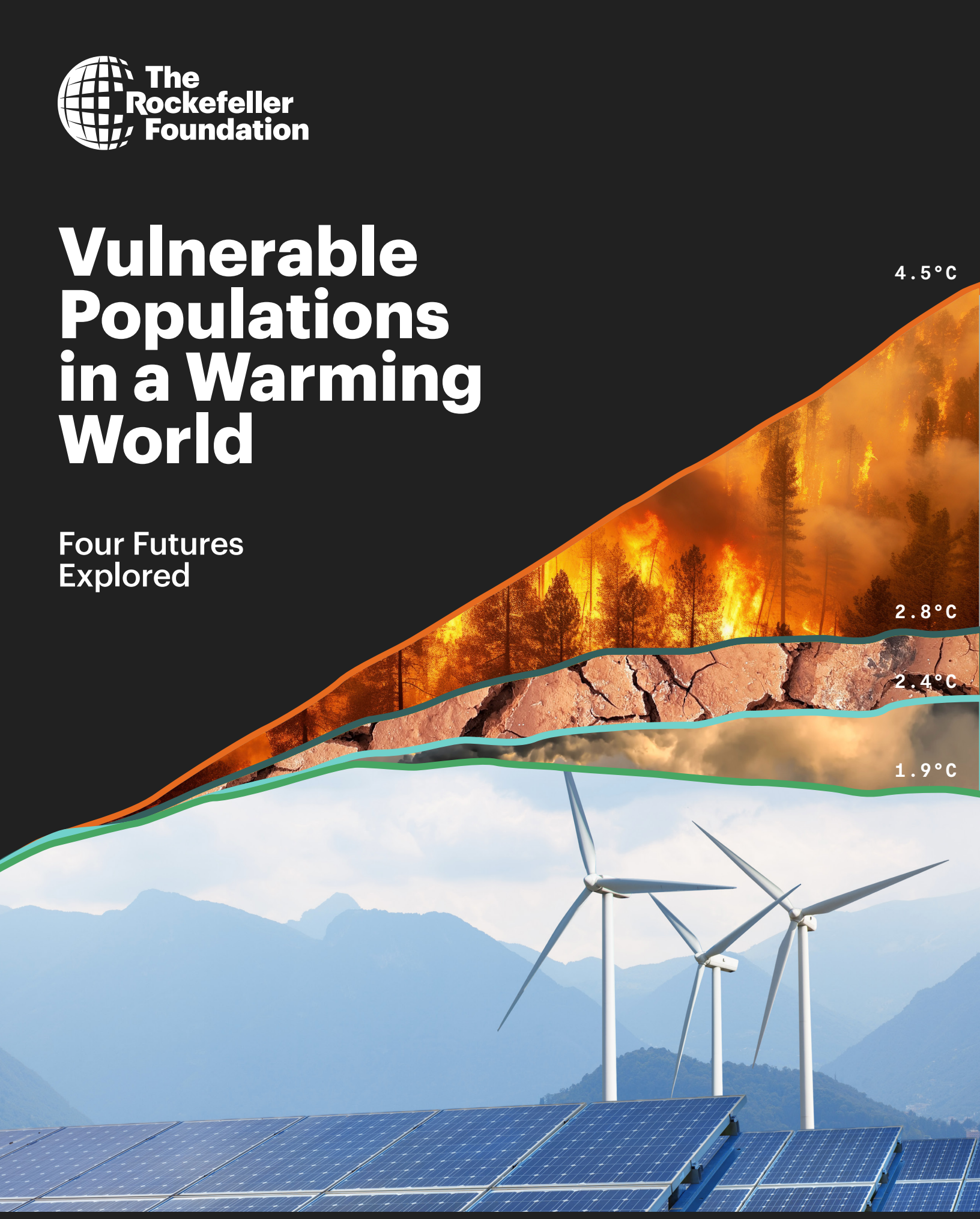
The Rockefeller Foundation

Vulnerable Populations in a Warming World

Four Futures Explored



Vulnerable Populations in a Warming World
Four Futures Explored

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With inputs from Rhodium Group and Catalyst Advisors

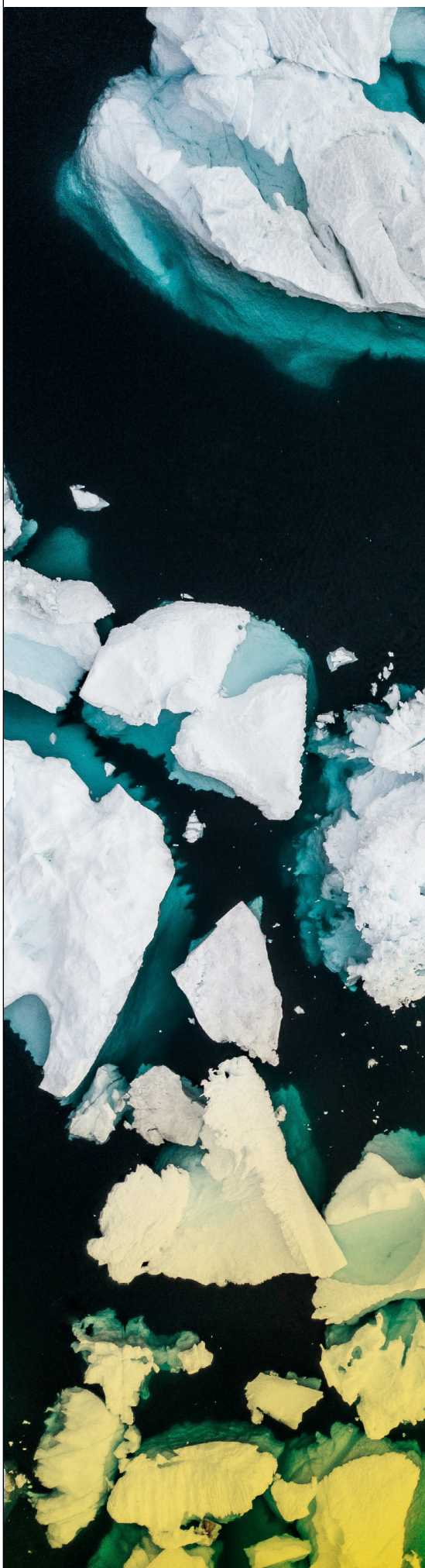
Foreword
Putting climate change front and center

For the past 110 years, data has helped drive the mission and focus of The Rockefeller Foundation. Measuring what works, and what doesn't, has informed our most impactful endeavors. When we resolved in 2022 to understand far better the impact of the climate crisis on our work and the people we serve, we scrutinized our programs, our spending priorities, and the available data.

This report is an example of that exploration. In it, we seek to examine what four plausible climate scenarios will mean for the planet and the people who inhabit it.

The data makes clear that current efforts to help people mitigate and adapt to climate change are insufficient. The "business as usual" scenario that best captures the track we're on now would result in at least 2.8 degrees Celsius of planetary warming over preindustrial levels by 2090. Such warming will be dramatically worse for those in the world's poorest and most vulnerable countries. Still worse would be the "climate catastrophe" scenario, in which global efforts to rein in emissions sputter and fall apart. That would result in at least 4.5 degrees Celsius of warming by 2090—an outcome that would severely alter life as we know it.

Fortunately, the data also illuminates a brighter path, one that would assure people survive and flourish. The scenario that assumes equal access to the latest in technological advances and global cooperation not only keeps warming in check, but also empowers the 3.6 billion people currently deprived of steady electricity—and, with it, economic opportunity.



As a result, this report is a reminder of the power of data to help clarify outcomes and avoid disaster. It makes clear that there is no workable strategy whereby the industrialized, affluent countries rapidly push to decarbonize while leaving poorer countries to fend for themselves. The only successful way forward on climate mitigation requires all regions and countries to work together.

It also illustrates the timeliness of The Rockefeller Foundation's 15-year work to help empower those who lack sufficient access to affordable, reliable electricity. Starting with solar mini grids in parts of rural India, the Foundation worked with partners to scale this solution to hundreds of villages across the country. We took that work worldwide in 2021 with the creation of the Global Energy Alliance for People and Planet, which was established with the IKEA Foundation, the Bezos Earth Fund, and other partners. The Alliance is now at work in more than twenty countries.

This report shows how imperative it is to try to find a path for successful climate mitigation that also expands opportunity for the world's neediest populations. But that route—the only workable route—requires urgency and resolve from all countries, sectors, and stakeholders.

And finally, the report reminds us that even amid a climate emergency and at a time of enormous global strain, it is realistic to be optimistic about our capacity to solve our biggest problems. When we follow the data, we can solve even the toughest, most complicated challenges.

Onwards,

Dr. Rajiv J. Shah
President, The Rockefeller Foundation

Executive Summary

Climate change marks a new era for The Rockefeller Foundation's global efforts

The world faces a looming climate emergency that threatens to alter life in all corners of the globe. Confronting that reality while opening opportunity for communities lacking access to energy will require unequaled focus, ingenuity, and determination. Apprised of that, The Rockefeller Foundation regards climate change as the singular challenge to its 110-year mission of promoting humanity's well-being throughout the world.

The Foundation is therefore committed to directly confronting climate change within our traditional program areas of energy, health, food, and equity.

To guide our work and to clarify the challenge for all concerned, with the support of Catalyst Advisors, the Foundation first created four distinct decarbonization scenarios based on divergent emissions pathways for developed, emerging and energy-poor countries. With support from the Climate Impact Lab at Rhodium Group, we then grappled with the impact of these scenarios for health, mortality, nutrition, and access to energy in every country in the world.

The key conclusions, which we elaborate below, are that no successful path to confront climate change can overlook the needs, vulnerabilities, and exposure of the world's energy-poor countries. The world can keep global warming under acceptable limits this century, but the strategy to do so requires global cooperation to support a boom in clean energy development in the 81 countries now lacking reliable power. A future in which the world's least developed countries modernize using power derived from fossil fuels, even as all other countries move to decarbonize, would push global temperatures beyond unacceptable limits, with dire consequences for human wellbeing.

This scenarios-based framework allows us to explore and compare different plausible futures and to pinpoint the actions and inactions that lead to them, as well as their impacts. This analysis sheds invaluable light on the potential pathways ahead and the consequences of picking one over another. It puts a particularly bright spotlight on how the least developed countries, having contributed the least to date to global carbon emissions, now face the gravest exposure to the impacts of climate change.

Four climate scenarios for the most vulnerable

The four scenarios we created with Catalyst Advisors represent divergent development and emissions pathways from three country groupings: developed economies, emerging markets and a third grouping of 81 "energy-poor" countries where annual electricity consumption per capita falls below 1,000 kilowatt-hours.

This approach makes it possible to highlight the glaring disparity in emissions to date and to lay out the implications of different courses of action for the most vulnerable countries and communities. It also reveals how each scenario meshes with the international commitment to keep global warming within safe limits.

The four scenarios we created are as follows:

1 GLOBAL COLLABORATION

Developed and emerging economies rapidly decarbonize while also supporting widespread decarbonization in energy-poor countries

+1.9°C
WARMING BY 2090

2 FOSSIL FUELS FOR THE POOR

Developed and emerging economies rapidly decarbonize, but energy-poor countries continue to rely on fossil fuels to support rapid economic development

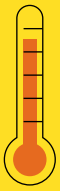
+2.4°C
WARMING BY 2090

3 BUSINESS AS USUAL

Past emissions trends for the three country groupings continue along their current trajectory

+2.8°C
WARMING BY 2090

4 CLIMATE CATASTROPHE



Global climate action halts as both developed and emerging economies opt for fossil fuel-based development, with no effort to reign in emissions

+4.5°C
WARMING BY 2090

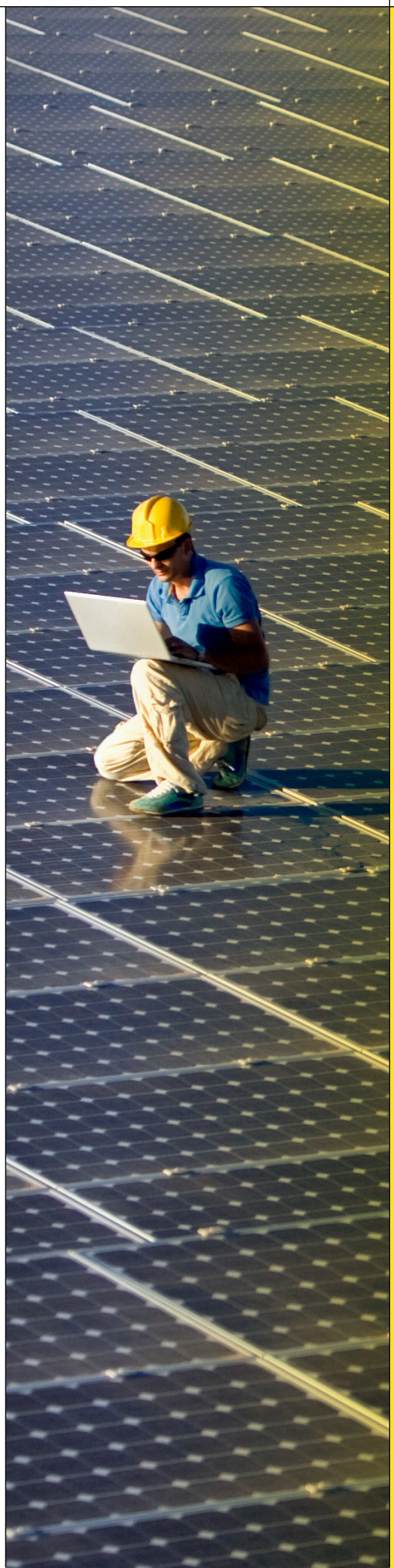
The implications for global efforts to avoid dangerous climate change

Our scenarios indicate global warming of between 1.9°C and 4.5°C by 2090, depending on how fast countries decarbonize and how extensively they collaborate to achieve widespread clean-energy deployment. All scenarios therefore surpass the carbon budget implied by the 2015 goal of "pursuing efforts" to limit warming to 1.5°C above pre-industrial levels, but only a scenario of immediate and sustained global collaboration would result in keeping global temperatures below 2°C and avoid the truly catastrophic consequences that higher temperatures will bring. Potential contributions from negative emission technologies – not accounted for in our scenarios – could yet be deployed at scale to close the gap to 1.5°C.

Implications for our efforts on behalf of humanity

To get a still more granular understanding of the repercussions within each scenario, we teamed up with the Climate Impact Lab at Rhodium Group, who used cutting edge econometric methods to explore the link between increased heat and socio-economic outcomes in 24,378 regions that span the world.[1] This deep level of analysis allowed us to forensically assess the implications of climate change for key areas of The Rockefeller Foundation's work: agriculture and food; health and mortality; and energy consumption.

1 The Climate Impact Lab's methodology divides the world into distinct regions, each containing roughly 300,000 people, in an effort to obtain the level of granularity needed to make meaningful comparisons across the various climate impacts. More here: https://impactlab.org/research/valuing-the-global-mortality-consequences-of-climate-change-accounting-for-adaptation-costs-and-benefits/



Key findings as follows:

Future economic impacts of climate change are projected to exacerbate existing disparity between regions and nations. Across all climate change scenarios, the world's energy-poor countries shoulder an outsized share for the negative impacts in all areas we measured, while the level of economic development shapes how well each country can respond to climate.

However, these impacts can be radically diminished with global action to reduce greenhouse gas emissions.

Agriculture and nutrition

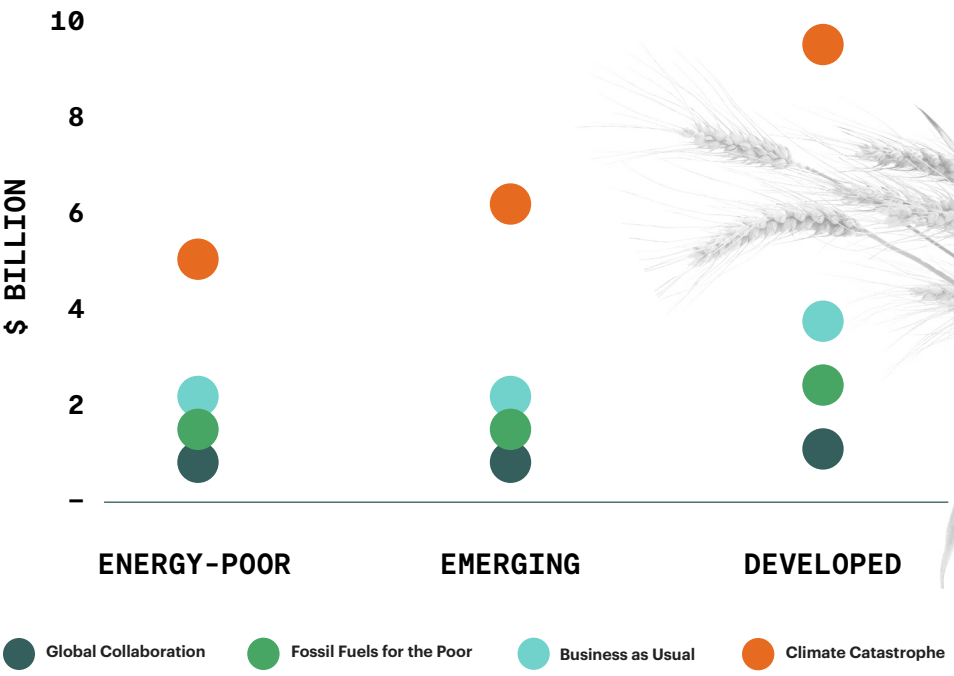
1 Each 1°C rise in global average temperature results in a daily loss of 130 calories per person.

2 In the most food insecure countries in the world, particularly in Africa, the loss to staple crop yields is on average two-thirds less in the Global Collaboration Scenario than in the Climate Catastrophe Scenario.[2]

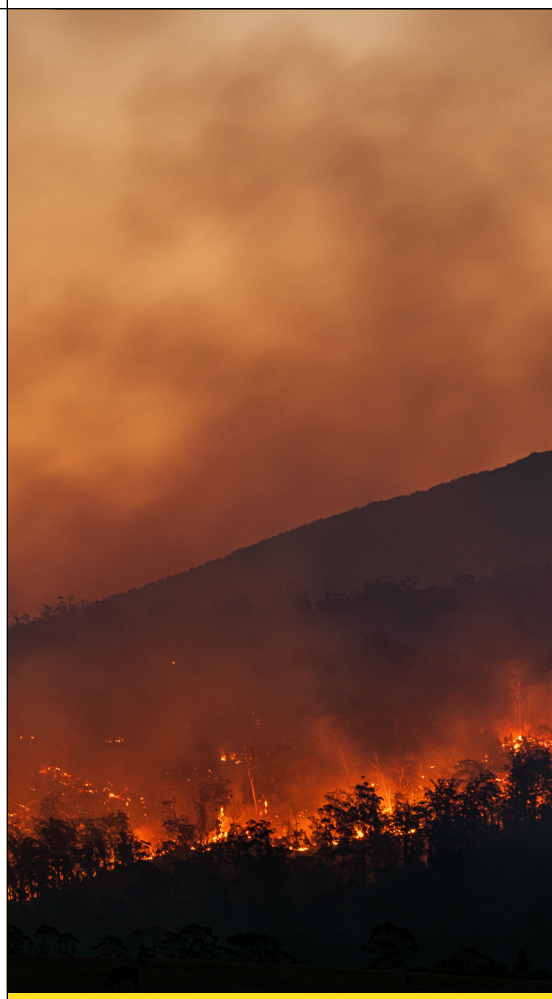
3 The negative impact on average agriculture yields across the six crops[3] we monitored is almost two-and-a-half times more severe in the worst-case scenario compared to the Global Collaboration Scenario.

4 By 2090, the net cost of reduced yields in developing economies in the Climate Catastrophe Scenario reaches over $360 billion, $226 billion more than in the Global Collaboration Scenario.

Average change in crop yield loss by country grouping and scenario



2 For the 10 most food insecure countries, including Congo, Sierra Leone, South Sudan, Haiti, Central African Republic, Malawi, Liberia, Comoros, Angola and Somalia.
3 Including cassava, corn, rice, sorghum, soy and wheat



Each 1°C rise in global average temperature results in a daily loss of 130 calories per person.

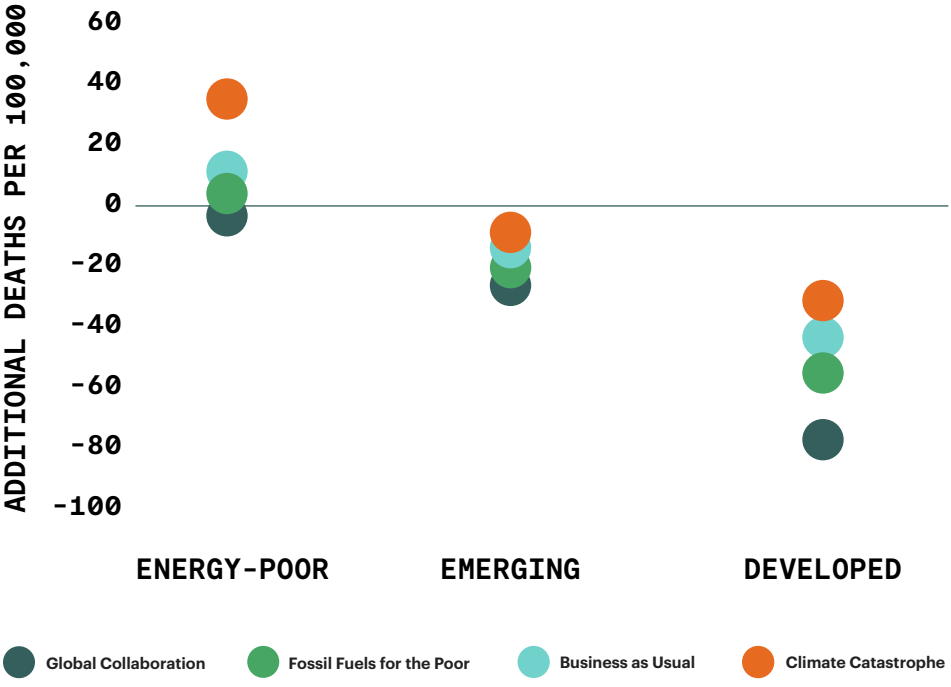
Health and mortality

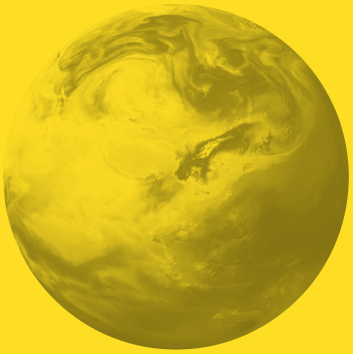
1 In both scenarios in which the global average temperature rises by more than 2.8°C, the world reaches a tipping point, reversing a historical pattern in which more deaths were attributed to cold weather than to warm temperatures.

2 The pattern of mortality is significantly different across country groupings, with a net increase in mortality in two-thirds of the world's energy-poor countries, compared to a net decrease in mortality in all but 10 of the 38 developed countries, even in the Climate Catastrophe Scenario.

3 Concerted efforts to mitigate climate change have a perceptible impact on the mortality rates of the world's poorest and most vulnerable. In the sub-Saharan countries of the Sahel, for instance, the mortality rates are eight-times lower in the Global Collaboration Scenario than in the Climate Catastrophe Scenario.

Average change in annual all-case death rate due to warming by country group and scenario (deaths per 100,000)





Concerted efforts to mitigate climate change have a perceptible impact on the mortality rates of the world's poorest and most vulnerable.

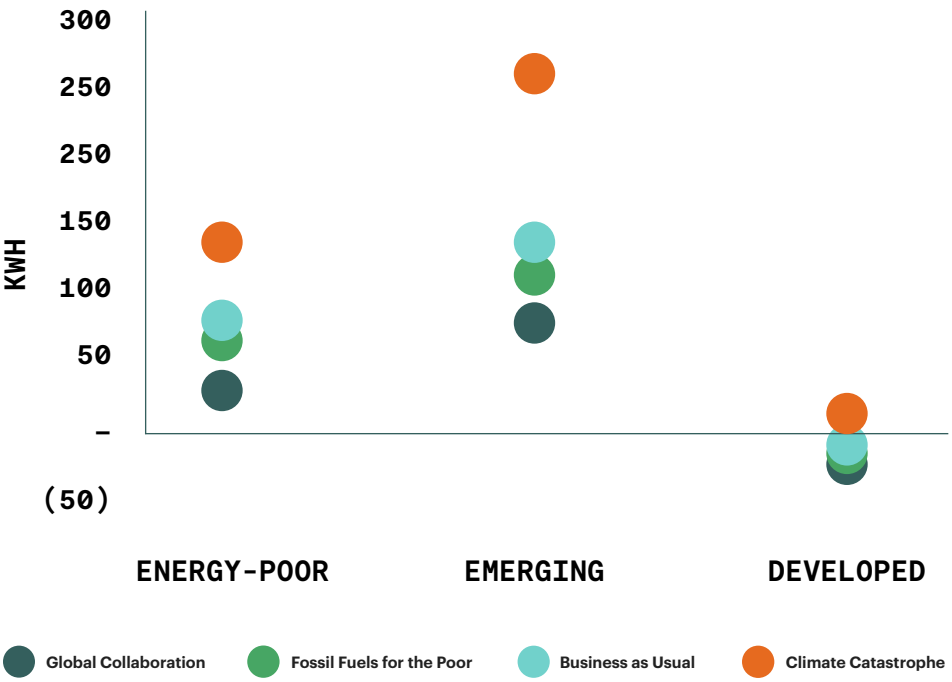
Electricity demand

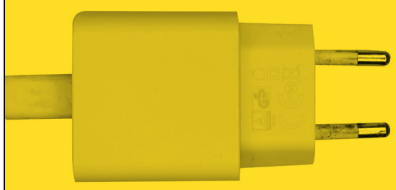
1 Among the world's 81 energy-poor countries, even in the most benign warming scenario, all but 10 will see increased demand for electricity linked to cooling. The extent of the increase varies widely across scenarios but is more than three-times as large per capita in the Climate Catastrophe Scenario as in the Global Collaboration Scenario.

2 This is in stark contrast to the impact on industrialized economies, which on average start with far lower average temperatures. More than half the developed economies (22 of 38) see a decrease in electricity demand due to less consumption in heating.

3 The rising demand for electricity for cooling has a material impact on power generation. The difference in demand between the Global Collaboration Scenario and the Climate Catastrophe Scenario by 2090 stands at 1,630 terawatt-hour (TWh), implying more than 1,105 additional new large power plants just to meet increasing demand linked to adapting to heat.

Average change in per capita electricity consumption by country group and scenario





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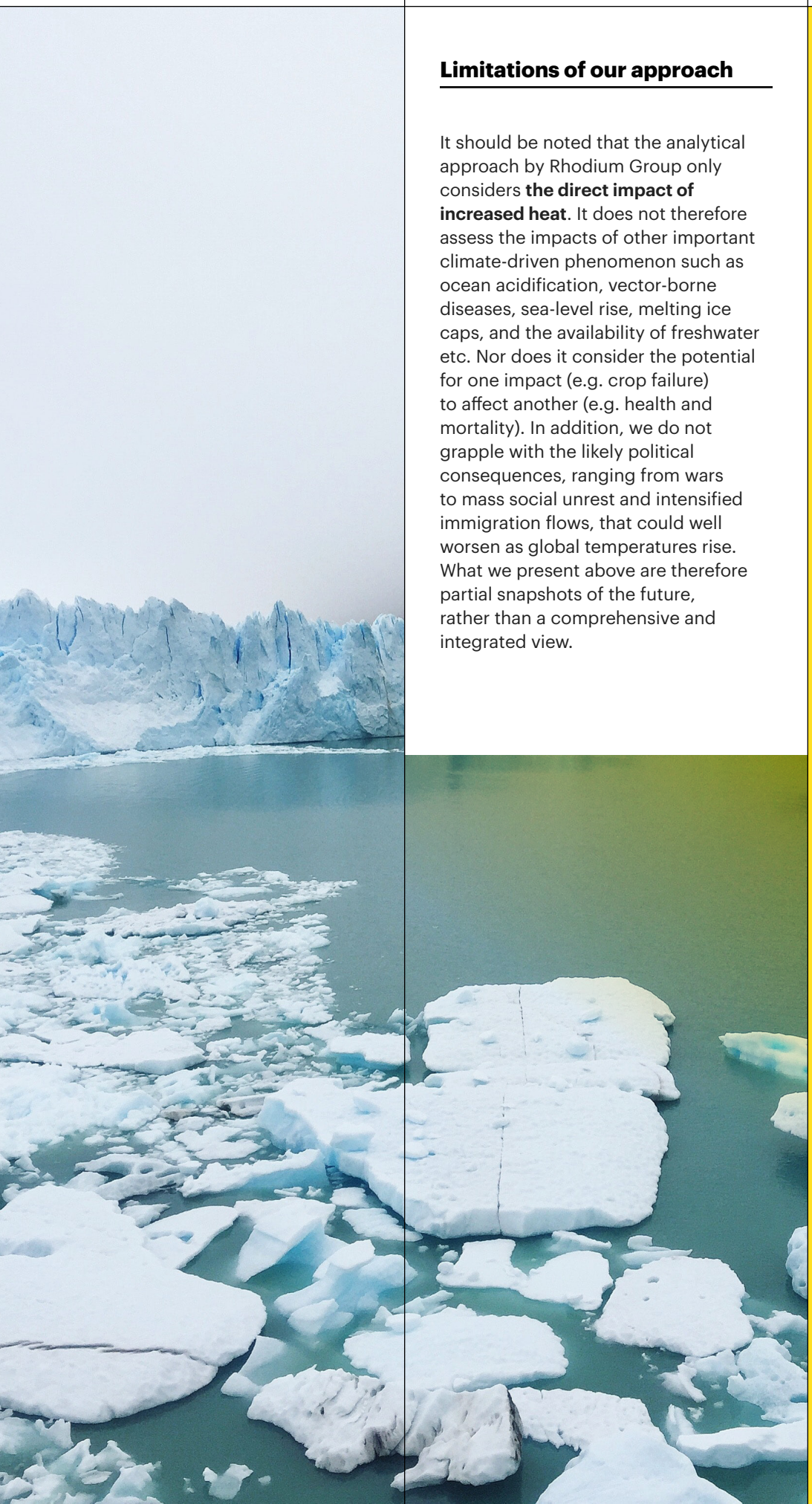


Limitations of our approach

It should be noted that the analytical approach by Rhodium Group only considers **the direct impact of increased heat**. It does not therefore assess the impacts of other important climate-driven phenomenon such as ocean acidification, vector-borne diseases, sea-level rise, melting ice caps, and the availability of freshwater etc. Nor does it consider the potential for one impact (e.g. crop failure) to affect another (e.g. health and mortality). In addition, we do not grapple with the likely political consequences, ranging from wars to mass social unrest and intensified immigration flows, that could well worsen as global temperatures rise. What we present above are therefore partial snapshots of the future, rather than a comprehensive and integrated view.

Conclusions

- The world can assure energy equity and economic opportunity for the least developed countries while effectively confronting climate change, but it must act swiftly and with true global cooperation to keep global temperatures from rising by 2°C over the course of this century.
- Any path that neglects the energy-poor countries results in significantly higher temperatures, with calamitous and unpredictable consequences.
- We must focus our mitigation efforts not only on the largest emitters of today, but also ensure that low-carbon technologies diffuse to low-income energy-poor countries to support clean development.
- Even under the best scenario, warming of the planet will begin to show deleterious impacts on key life metrics. Yields of wheat for the top 10 exporting countries will fall by 15%, for instance. And all but 10 of the energy-poor countries will see rising demand for electricity due to cooling.
- With every degree of additional warming, energy-poor countries suffer rising food insecurity and rates of mortality.

Introduction

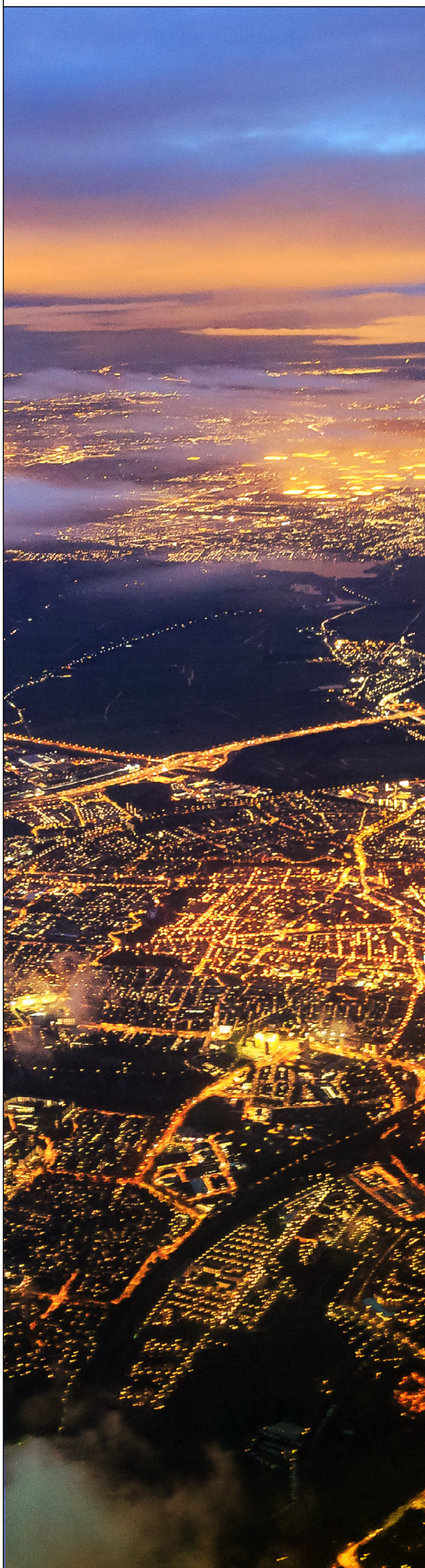
Until recently, climate protection was seen to stand in conflict with economic development and the mission to end energy poverty. Of the 1.2 billion people who gained access to electricity since 2000, nearly all did so by connections to the main grid, and 70% of the power generated for these new connections came from fossil fuels, adding significantly to greenhouse gas emissions.[i]

The world is at a crossroads now that promises to open vistas for progress on both fronts. Over the past decade, technological and market progress has created the prospect for an entirely new economic model. The transition of power systems to clean and distributed energy in the 81 countries we describe as "energy-poor" [What we mean by energy-poor countries] has the potential to be a central plank not only of economic development and jobs creation but also in combating climate change. The transition to clean energy in these countries not only presents huge opportunities for global climate action but appears to offer the only path to keeping global temperature increases to under 2°C this century.

But despite the promise of a green transformation, energy-poor nations, which are home to nearly half the world's population, are being left behind. While renewables are booming, only 6% of wind and solar photovoltaics was deployed in these countries in 2021, of which only 0.6% went to Africa.[v]

We have also arrived at a moment where climate change is bearing down on humanity, and the impacts are already playing out in dramatic and deadly fashion in all parts of the world, as this year has so vividly shown. According to the Intergovernmental Panel on Climate Change (IPCC), "Cumulative future CO_2 emissions over the lifetime of existing and planned fossil fuel infrastructure are approximately equal to the remaining carbon budget for limiting warming to 2 degrees". Without dramatic changes, it will soon grow beyond humanity's hope to control.

It is essential to note that the carbon budget is exhausted largely due to the historical contribution of developed economies, who together are responsible for 59% of total historic carbon emissions. Emerging economies, a large and diverse group of some 70 middle-income countries, are responsible for 33% of emissions concentrations.



Approximately 3.6 billion people live in energy poverty across 81 countries.

What we mean by energy-poor countries

Access to power has become central and indispensable to modern life: nothing is more predictive of extreme poverty than lack of access to electricity, and nothing does more to alleviate poverty than providing that access. For many of the world's poor, the key impediment to their entry into a modern economy is the inability to plug into a reliable source of power.

For this reason, the U.N. Sustainable Development Goal 7 calls for *"access to affordable, reliable, sustainable and modern energy for all"*. Yet the principal indicator of that goal is the residential electrification rate of a minimum of 50 kilowatt-hours (kWh) per capita per year. This level of consumption is in no way sufficient to sustain economic development and to open the doors of economic opportunity to the citizens of energy-poor countries. For a country to reach lower middle-income status requires a Modern Energy Minimum (MEM) of about 1,000 kilowatt-hours per annum to be achieved. This is inclusive of both 300 kWh of household and 700 kWh of non-household electricity consumption.[ii]

Using this threshold as a proxy for energy poverty, we estimate that approximately 3.6 billion people live in energy poverty across 81 countries: 75 of these countries have not reached a MEM and another 6 have grids that are so unreliable that they constitute an impediment to development.[iii]

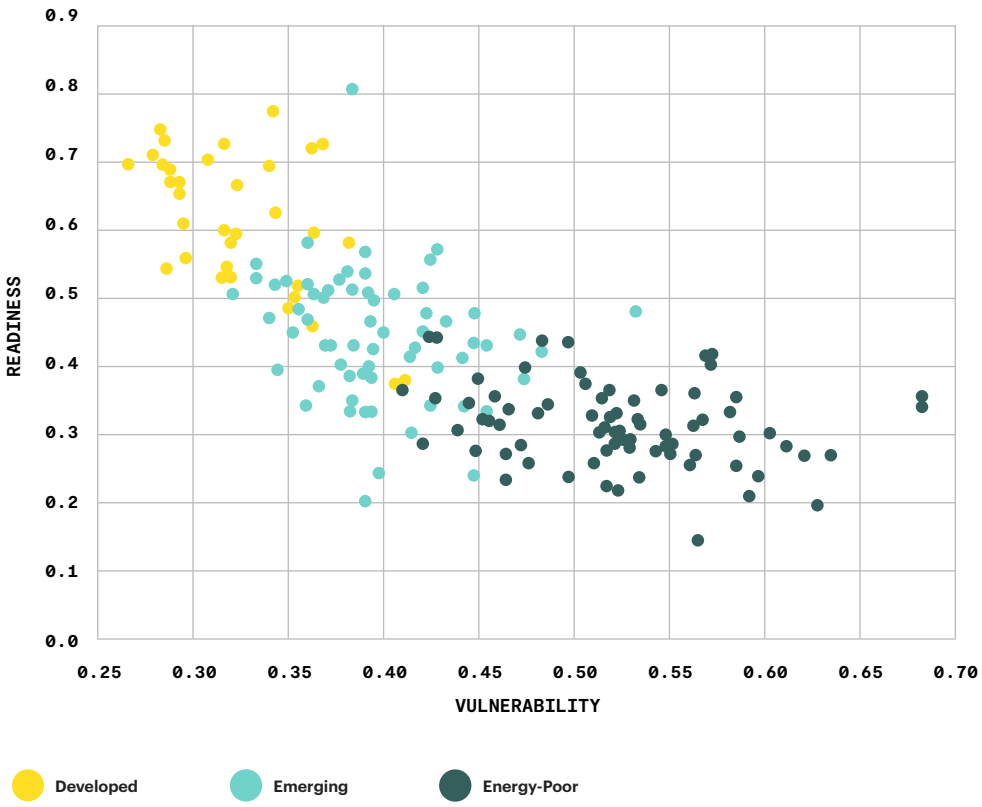
This set of 3.6 billion people falls into three subsets. The most deprived group are the 838 million people that have no electricity whatsoever, almost 609 million of whom live in sub-Saharan Africa. An additional 1.45 billion people have unreliable or unstable access (and are also energy-poor), while approximately 1.3 billion people have a reliable connection, but their level of power consumption remains a severe impediment to progress.[iv]

i. See: https://www.iea.org/reports/energy-access-outlook-2017
ii. For more details on the modern energy minimum", see: https://www.energyforgrowth.org/wp-content/uploads/2021/01/SHORT-Modern-Energy-Minimum-Final-Jan2021.pdf
iii. Unreliability is defined here as more than 12 hours of outage per month. These countries are South Africa, Gabon, Iraq, West Bank, Dominican Republic and Guyana.
iv. Estimate provided by Catalyst Advisors, November 2020
v. Assessment of IRENA data by Catalyst Advisors, 2023
vi. https://gain.nd.edu/assets/254377/nd_gain_technical_document_2015.pdf

By contrast, the 81 energy-poor countries are responsible for just 8% of the emissions currently accumulated in the atmosphere. Ironically, as we explore in depth in this report, it is by and large this energy-poor cohort of countries that are most vulnerable to climate impacts across six life-supporting sectors: food, water, health, ecosystem services, human habitat, and infrastructure. This is because these countries tend to be more exposed to climate impacts, more sensitive to these impacts, and far more lacking in adaptative capacity. Middle-income and high-income countries tend to be more insulated from climate impacts and better positioned to adapt.

This is clearly demonstrated by the ND-GAIN Country Index, which summarizes a country's vulnerability to climate change in combination with its readiness to improve resilience. It illustrates that the energy-poor group of countries that have contributed the least to climate change tend to have the most to lose from a warming planet and are the least ready to respond, whereas emerging and developed economies tend to be more insulated from climate impacts and better positioned to adapt.

Vulnerability to climate impacts and readiness to respond by country grouping



Source: RF analysis of ND-GAIN Data (2022)

Against this backdrop of continued and widespread energy poverty and looming climate emergency, The Rockefeller Foundation in July 2022 identified climate change as posing a singular threat to achieving its 110-year mission of promoting humanity's well-being throughout the world. The Foundation thus committed to combating the threat across its traditional program areas of health, power, food, and equity.

As a result, we undertook this scenarios exercise to more fully understand the dynamics of responsibility for climate action and the technological potential and vulnerability for climate change among starkly different sets of countries. We knew the results would help inform our ongoing climate strategy but also amplify the world's understanding of a hugely complex challenge.

A central motivation that spurred this analysis was understanding the contribution to and implications of climate change among the most vulnerable energy-poor countries and communities. We sought to explore what the future could look like if the energy-poor world based their industrialization and development in the century ahead largely on fossil fuels, thereby following in the pathway of every advanced and middle-income countries before them.

We wanted to investigate what the impact on climate change would be and compare this to an alternative future in which developed, emerging and energy-poor economies collaborated to ensure the more equitable flow of capital and clean technologies.

And we wanted to grasp how the impacts of climate would differ in these plausible alternative future worlds for energy-poor, emerging and developed nations. The ultimate objective was to assess the strategic implications for the Foundation's mission to make opportunity universal and sustainable in the century ahead, and for our programmatic priorities of health, power, food, and equity.

To this end we engaged Catalyst Advisors to co-develop with our teams four plausible climate scenarios, and we engaged Rhodium Group's Climate Impact Lab to assess the implications of these scenarios for different country groups and individual countries. In this report we share what we learned.

We believe this approach will help challenge existing assumptions and identify novel lines of inquiry against a backdrop of complexity and uncertainty. At the same time, we hope this analysis will assist in illuminating both vulnerabilities and opportunities, and the actions and inactions that can influence them.

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Why Scenarios?

We are wrestling here with several interrelated trends, starting with different levels of greenhouse gas emissions for different groups of countries and the resulting planetary warming. From there we must grapple with the implications for development, especially for the most vulnerable countries and communities, while also taking into account the increased competitiveness of clean-energy technologies and how their deployment is likely to vary sharply by region.

These underlying trends, with all their complex interactions, undermine the efficacy of any predictions drawn from them. Scenario analysis, on the other hand, steps away from making predictions or projections. It aims to identify critical uncertainties and develop plausible long-term scenarios in a manner that allows us to explore the future in a sober and analytical fashion. A key appeal of the scenarios approach is it avoids fatalism, pessimism or even optimism by exploring different futures side by side, on an equal footing.

The framework we describe below allows us to explore and compare different plausible futures. It allows us to pinpoint the actions and inactions that lead to these different futures. It is true that some of the scenarios we describe may seem less likely than others, but it is worth considering whether they could be possible, and if so, what factors lead in that direction. This work therefore allows us to engage our imagination as well as our critical faculties and challenges us to create the future world we would like to fashion for ourselves and coming generations.

The framework of our four scenarios

The four scenarios described below were built on different underlying assumptions about how energy demand, fossil fuel use, and thus CO_2 emissions evolve in developed, emerging, and energy-poor countries – in effect, how fast these groups of countries achieve net-zero emissions.

Critically for The Rockefeller Foundation, this framework – looking at three groups of countries, and the implications in health, food, power, and jobs in a warming world – allows us to explore our core ambition, which is to make opportunity universal and sustainable. This framework allows us to focus on issues of equity, climate justice, and poverty, and to explore the implications of our choices for the poor and vulnerable, and their access to energy, food, and good health.

Below we describe each of these scenarios along with the assumptions underpinning them and their implications for planetary warming in the century ahead.

Scenario assumptions and descriptions

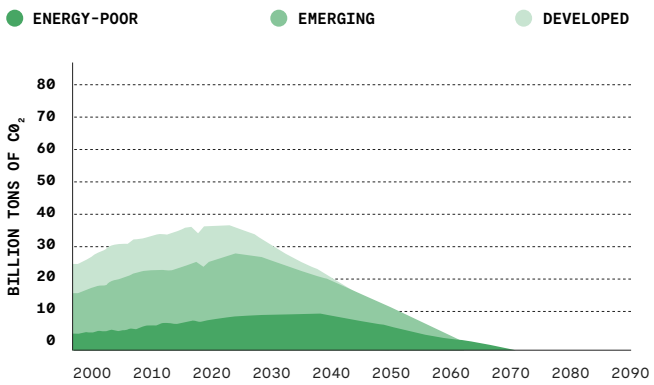
For each scenario, we leveraged the formulae behind the carbon budgets outlined in the IPCC's Sixth Assessment report (AR6) to estimate the expected maximum average temperature increase at the 67% confidence level for different greenhouse gas emissions in the atmosphere.

It aims to identify critical uncertainties and develop plausible long-term scenarios in a manner that allows us to explore the future in a sober and analytical fashion.

1 GLOBAL COLLABORATION

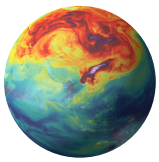
this results in circa 1.9°C warming by 2090

GLOBAL COLLABORATION

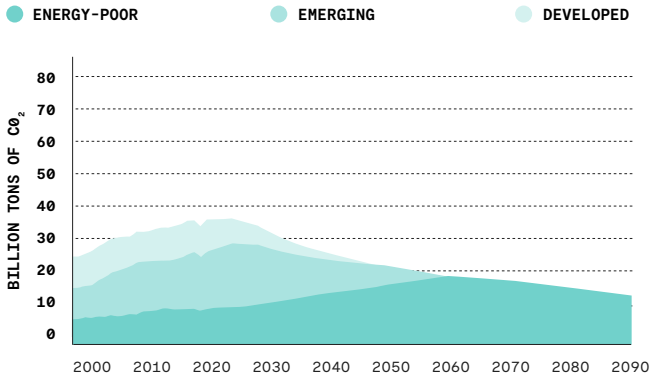


2 FOSSIL FUELS FOR THE POOR

this results in circa 2.4°C warming by 2090



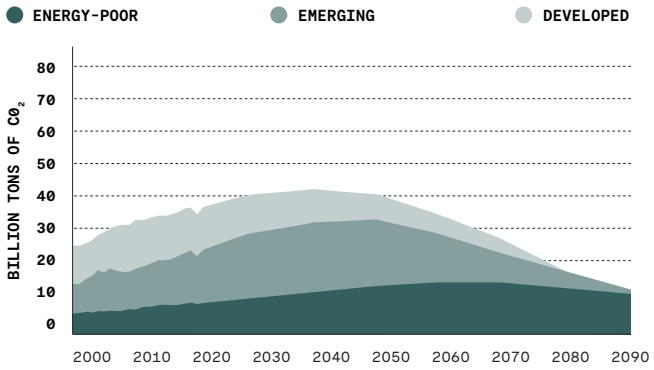
FOSSIL FUELS FOR THE POOR



3 BUSINESS AS USUAL

this results in 2.8°C warming by 2090

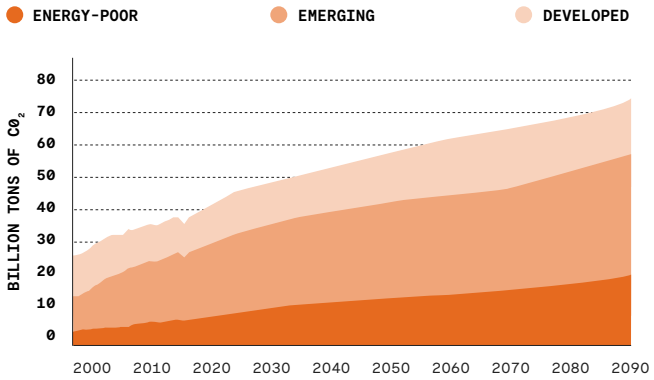
BUSINESS AS USUAL



4 CLIMATE CATASTROPHE

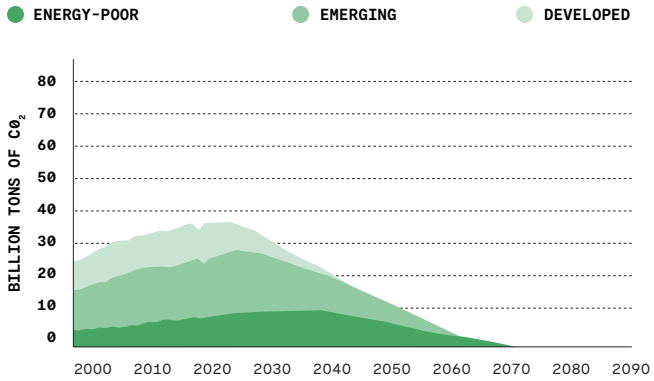
this results in circa 4.5°C warming by 2090

CLIMATE CATASTROPHE



1 GLOBAL COLLABORATION

THIS RESULTS IN CIRCA 1.9°C WARMING BY 2090

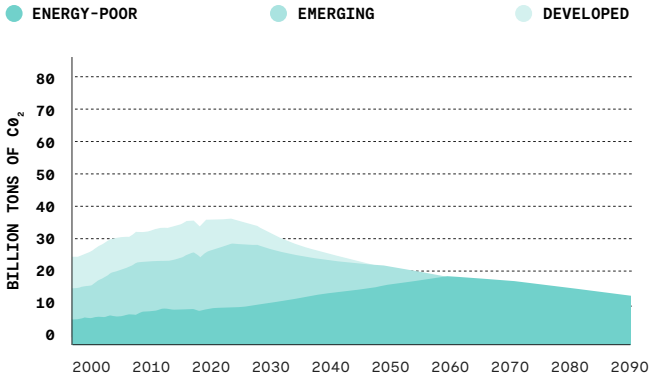


The Global Collaboration scenario illustrates a future where developed and emerging economies get serious about addressing GHG emissions within their borders, while also redoubling their efforts to ensure that energy-poor countries have access to both the capital and technology required for them to decarbonize as they grow out of energy poverty. Developed economies immediately ramp up mitigation efforts in a manner consistent with their announced carbon pledges under the Paris Agreement, allowing them to meet their 2050 net zero targets. Emerging economies like China also take measures to implement their own net-zero pledges, with the late 2020s marking a clear inflection point followed by significant emissions reductions, leading to a net zero outcome in 2060.

In this scenario energy-poor countries also receive sufficient financial, technological, and technical support to rapidly scale deployments of renewable energy resources within their own economies. This allows them to escape energy poverty by 2040 and to decarbonize in parallel. The result is that emissions in these countries peaks in 2040, with net-zero emissions achieved by 2070.

2 FOSSIL FUELS FOR THE POOR

THIS RESULTS IN CIRCA 2.4°C WARMING BY 2090

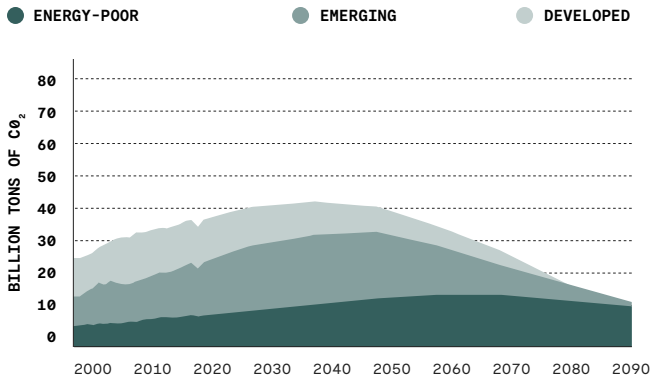


The Fossil Fuels for the Poor scenario illustrates a future where developed and emerging economies get serious about addressing GHG emissions within their borders but do little to ensure that energy-poor countries have access to both the capital and technology required for them to decarbonize as they grow out of energy poverty. The pathway followed by developed and emerging economies is identical to “Global Collaboration” – these country groupings decarbonize their economies in line with their net zero pledges for 2050 and 2060 respectively.

In this scenario, however, emissions from the energy-poor grouping of countries grows rapidly as they exploit abundant and lower-cost fossil fuel resources that are out of favor in other markets. This allows them to grow out of energy poverty by 2040 at the expense of considerably higher emissions. Three quarters of all global emissions come from energy-poor countries by 2050 in this scenario. In effect, this scenario envisages clean energy for the rich and fossil fuels for the poor.

3 BUSINESS AS USUAL

THIS RESULTS IN CIRCA 2.8°C WARMING BY 2090



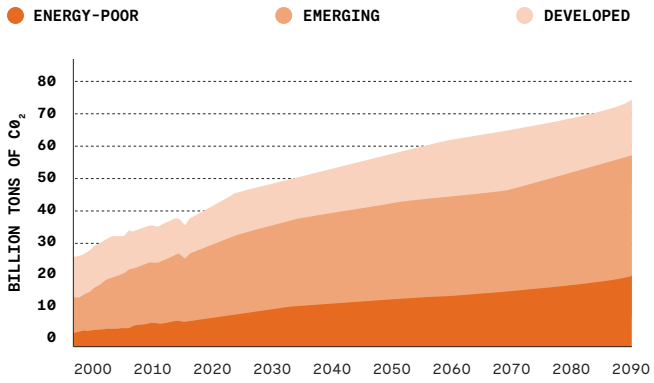
In Business as Usual, nations act too slowly to stave off a climate emergency without addressing energy poverty. We call this scenario Business as Usual because the core assumption is that trends in emissions growth and energy use over the past decade are the most reliable predictor of future developments for our three country groupings – developed, emerging and energy-poor countries – through to 2030. Thereafter, decarbonization accelerates gradually thanks to the greater availability of cost-effective low-carbon technologies.

In this scenario, developed economies' emissions footprints decrease gradually over the next two decades, but it's not until the 2040s and 2050s that they really ramp up decarbonization efforts. As such, they achieve net zero emissions only in 2080. Emerging economies also take longer to ramp up decarbonization efforts, with emissions plateauing only in 2040, pushing out net zero dates to 2090-2100. Meanwhile, energy-poor country emissions also grow slowly in line with recent historical trends up until 2060, before leveling off and eventually declining to net zero by 2150. This scenario depicts a future in which many of these countries remain energy-poor in the short to medium term, thus leaving them particularly unprepared to adapt to the catastrophic climate change brought on by such an emissions trajectory.

While this is certainly not a worst-case scenario, it perhaps best represents the trajectory the world is currently on.

4 CLIMATE CATASTROPHE

THIS RESULTS IN CIRCA 4.5°C WARMING BY 2090



Climate Catastrophe illustrates a future where the efforts made by many countries to rein in their emissions drops off significantly, possibly because of serious fragmentation of the world order and a rise in protectionism. The Paris Agreement and other mechanisms for engendering international cooperation and trade fall into abeyance, giving rise to a resurgent and persistent increase in the use of fossil fuels, in particular coal, as countries strive to utilize abundant local resources rather than rely on fragile international supply chains.

For developed economies, instead of continuing to reduce emissions by approximately 1% annually, emissions instead grow at a rate of approximately 1% annually through 2030, and then continue to grow at under 1% for the rest of the century. For this group, emissions peak by the end of the century, before beginning a slow decline. For emerging and energy-poor countries, emissions growth continues at about 3% per annum until 2030, before falling to about 1% per annum for the rest of the century, implying strained economic growth and continued dependence on fossil fuels, especially coal. Globally, net-zero emissions is not achieved until 2250. In this scenario many developing countries remain energy-poor in the medium term, all the while experiencing increasingly devastating climate impacts.

It is worth noting that global CO_2 emissions in 2022 were 14% under the climate catastrophe pathway, partly because of the Covid-19 pandemic. This scenario therefore requires a significant reversal of decarbonization trends achieved in some countries over the past decade. It can be considered “worst-case”.

All scenarios therefore surpassed the carbon budget implied by the 1.5°C degrees trajectory, but only a scenario of immediate and sustained global collaboration would result in capping emissions below the 2°C target.

Change in global mean surface temperature (°C) relative to 1850-1900 average, by scenario

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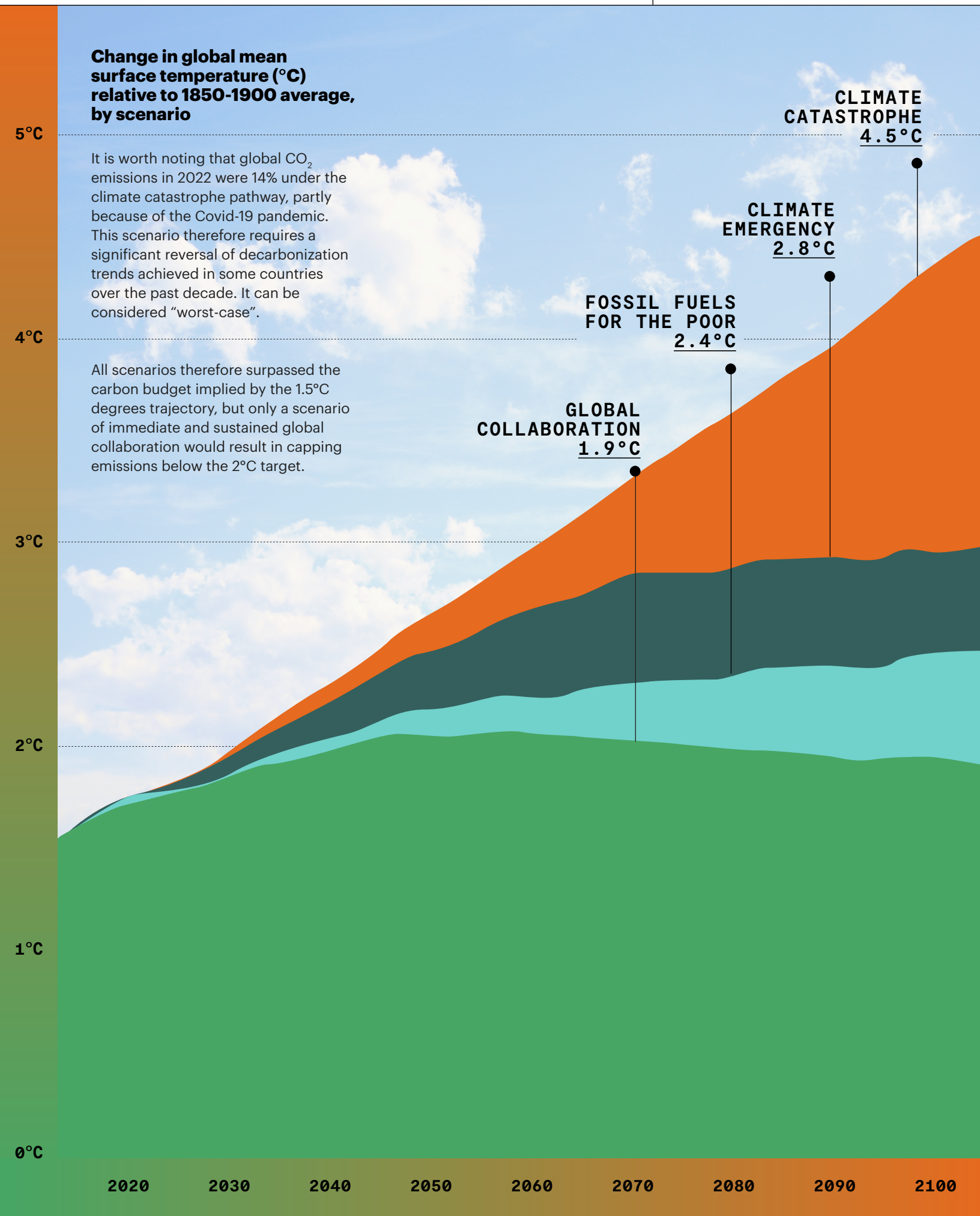

Assessing the Impacts

We employed Rhodium Group Climate Impact Lab's empirical climate impact modelling approach to simulate the impacts of climate change on human welfare under the four scenarios outlined above. Using these parameters, future physical conditions are mapped under each pathway at a high geographic resolution through 2090. We then analyze how populations in each of the world's countries respond to changing climate conditions in multiple time horizons, focusing on the impacts of heat on:

- **Agriculture and food**
- **Health and mortality**
- **Energy consumption**

It should be noted that the approach by Rhodium Group only considers **the direct impact of increased heat**. It does not therefore assess the impacts of other important climate-driven phenomenon such as ocean acidification, vector-borne diseases, sea-level rise, melting ice caps and the availability of freshwater, etc. Nor does it consider the potential for one impact (e.g. crop failure) on another (e.g. health and mortality). Finally, it does not assess the implications of these impacts on human systems and institutions (e.g. the implications of these impacts on conflict, political upheaval, immigration, etc.).

What we therefore present below might best be considered a partial glimpse into the future offered from looking through a lens with a very narrow and tightly focused aperture. The reality, particularly in the more extreme scenarios, would likely be considerably worse as eroding living standards added to mass social unrest.

Impacts of excess heat on agriculture and food

Even a "modest" rise in global average temperatures will result in broader changes to weather patterns. This will be reflected in increasing precipitation in some areas and diminished rainfall in others, with potentially significant impacts on agriculture either way. Higher temperatures can also directly affect crop development and yield, as crops rely upon fixed temperature ranges for optimal growth. In some conditions, heat stress reduces photosynthesis, lowers yields, and increases plant susceptibility to pests and diseases.

Across all the scenarios that we modeled, every region in the world is projected to experience a net decrease in total calories produced across the six staple crops we observed (cassava, corn, rice, sorghum, soy, and wheat). However, the impact on crop yields rises commensurately with heat across the scenarios: with each 1°C rise in global average temperature resulting in a daily loss of 130 calories per person. This implies that, at a temperature rise of 4.5°C, the calorie loss per person across the world would amount to around 30% of the daily recommended total (of 2,000 calories).

The impacts of falling yields due to heat will, by definition, be felt most acutely in areas already facing food insecurity. This puts Africa, which is home to 23 of the 25 most food insecure countries in the world (FAOStat), in the crosshairs. When examining the risk in the most food insecure countries, we found that crop yields of the staple crops in each could typically fall by half in a Climate Catastrophe Scenario. Such losses could have much broader ramifications across a range of development indicators, leading to reduced cognitive and motor development in children,[5] and diminished output from the labor force.

As crop losses rise, vulnerable countries will increasingly look to imports to meet demand. However, rising heat will also have deleterious effects on the world's largest exporters of the key crops. Across the countries that are currently the top ten exporters of wheat, for example, the average yield falls somewhere between 15% and 35% depending on the scenario. Crop yield falls in this range translate to higher food prices globally, heightening the possibility of outright shortages, pushing up consumer price inflation, and further straining budgets for importing countries.

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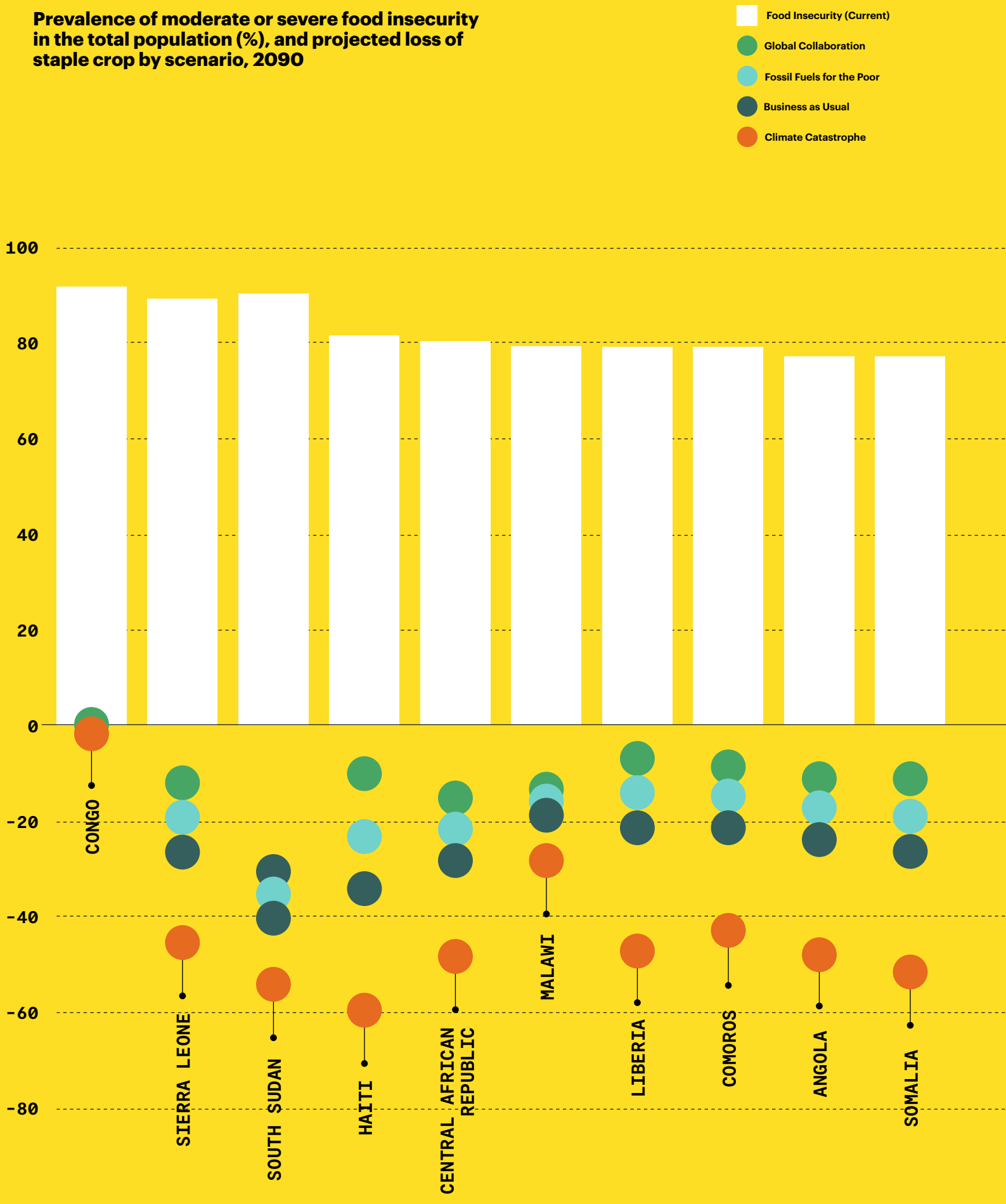
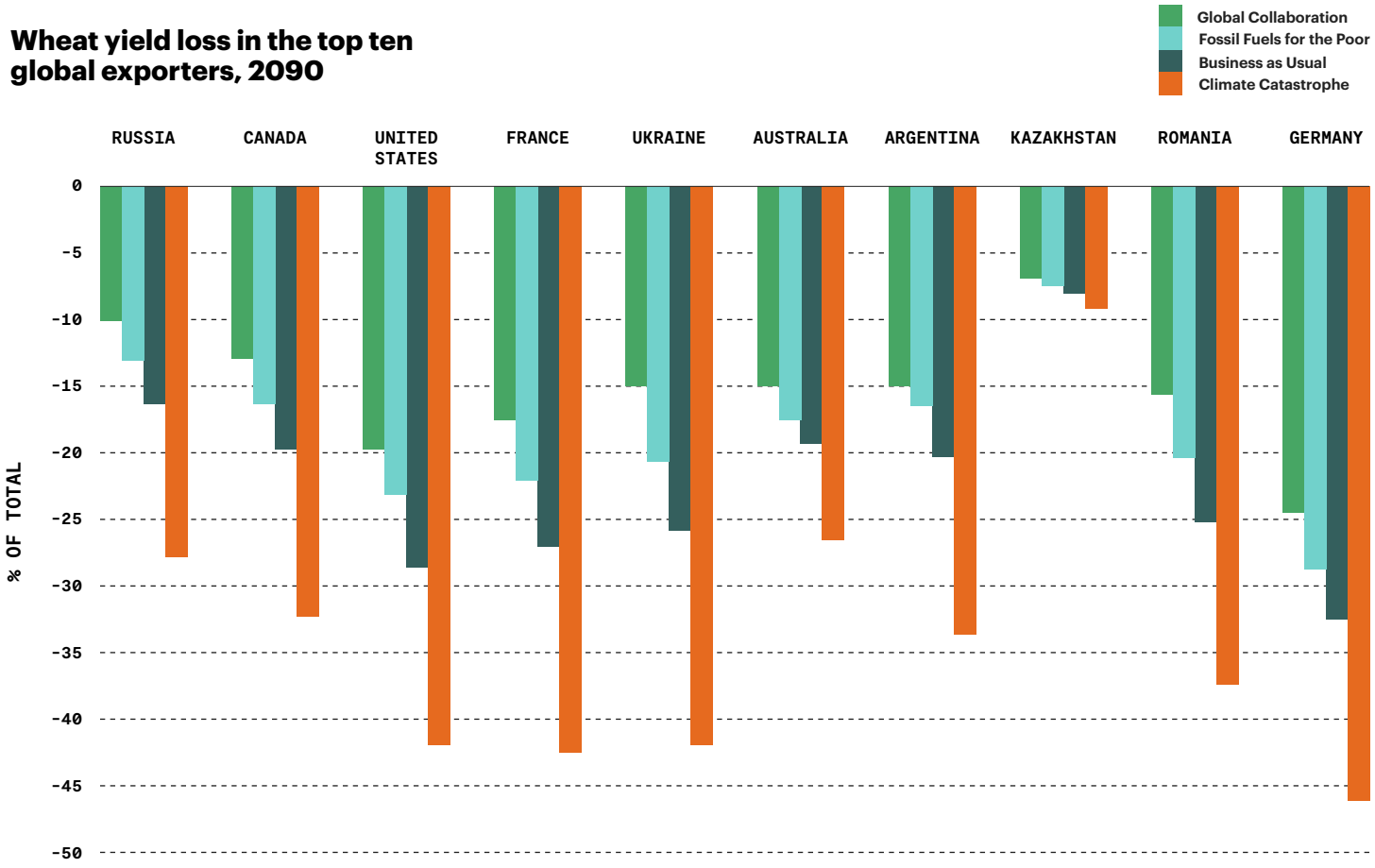
4 Various studies have shown that educational attainment and nutrition are strongly correlated. See Amogha Shree, M.R. Narayana Murthy, Impact of malnutrition on scholastic performance among school children in Mysuru and Zerga AA, Tadesse SE, Ayele FY, Ayele SZ. Impact of malnutrition on the academic performance of school children in Ethiopia: A systematic review and meta-analysis.
5 FAOStat

Prevalence of moderate or severe food insecurity in the total population (%), and projected loss of staple crop by scenario, 2090



Wheat yield loss in the top ten global exporters, 2090



In effect, such severe losses to crop yields would imply a more pronounced, fundamental, and systemic version of the pressures the world saw following Russia's invasion of Ukraine. Africa is, again, the most vulnerable to these secondary effects of diminished food trade by virtue of countries in the continent being among the most reliant on food imports. Food imports account for almost 40% of total merchandise imports in Benin, around 30% in the Democratic Republic of Congo, and are over 20% in Senegal, Mauritius, Gambia, Mauritania, and Ethiopia.[6] This means that food prices play an outsized role in the health of those economies, being a conduit for inflation and even currency pressures due to balance of payment impacts.

Rapid, concerted action to mitigate climate change would have a discernible impact on reducing risks to global agriculture. In assessing the potential losses to the yields of the staple foods of the world's most food insecure countries, we find that efforts to avert warming could reduce losses by an average of two-thirds, for example. By 2090, the net annual cost of reduced yields in developing economies in the Climate Catastrophe Scenario reaches $226 billion more than that in the Global Collaboration Scenario.

6 World Bank https://data.worldbank.org/indicator/TM.VAL.FOOD.ZS.UN?most_recent_value_desc=true

Impacts of excess heat on health and mortality

Global warming will dramatically change the historical patterns of health and mortality going forward. In each of the 20 years between 2000 and 2019, it is estimated that over 5 million people around the world died due to "non-optimal" temperatures, with over 90% of these linked to excessive cold weather.[7] Both the Business as Usual and Climate Catastrophe Scenarios of this study result in a profound shift in this historical pattern in the coming decades, with the negative impact of warming more than offsetting the reduction in cold-related mortalities.

This is crucial because hot days (where the average temperatures rise above 35°C) have typically proven worse for global public health than cold days (below -4°C). On average, a single hot day increases mortality rates by 4 deaths per 1 million people, while a cold day increases the mortality rate by 3 deaths per 1 million people.[8]

As temperatures rise, the impacts will be felt in varying ways across different regions, highlighting one of the most profound inequities of the impacts of climate change. The world's energy-poor countries, which start, on average, with a warmer baseline temperature and with less access to the infrastructure, healthcare and cooling that can mitigate the effects of heat waves, again suffer an outsized burden.

In aggregate, more than 2 in every 3 of the world's energy-poor countries suffer increases in mortality rates in the Climate Catastrophe Scenario, with the impact felt most acutely in the already warm regions of Africa and Asia. The net impact on this group is a rise of 36 deaths per 100,000 per year by 2090, but this belies significant variance, with the worst affected countries, like Djibouti, seeing excess heat-related deaths rising by 215 per 100,000 — almost 3 times the average global rate of temperature related mortalities today.[9]

This is in stark contrast to what happens in richer economies: of the 38 developed economies we analyzed, all but 10 see a decrease in mortality due to warming in the Climate Catastrophe Scenario. This is because these countries tend to be in temperate climate zones, and indeed because they have a higher adaptative capacity. Those where mortality rates do go higher see a rise of 25 deaths per 100,000; around one-fifth the net improvement in the rest of the group.

Concerted climate action, as in the Global Collaboration Scenario, would serve to drastically blunt the negative impact of heat on health in the energy-poor countries. In this scenario, 61 of 82 energy-poor countries see a decrease in total mortality rates, with the remainder experiencing only modest increases. Reaching the Modern Energy Minimum in all countries across the world means that in the Fossil Fuels for the Poor Scenario, there is an increased ability to deal with excessive heat, mitigating greatly the health impact.

In all instances, the countries in the Sahel (and adjacent to it) are consistently the most vulnerable – accounting for 8 of the top 10 most afflicted countries, but here too, the mortality rates are up to eight times lower in a scenario where temperature rises are limited to below 2°C, compared to one where global warming is kept unchecked.

7 Zhao Q, Guo Y, Ye T, et al., 2021. Global, regional, and national burden of mortality associated with non-optimal ambient temperatures from 2000 to 2019: a three-stage modelling study. Lancet Planet Health.

8 Rhodium Group and Carleton et al., 2022

9 For comparison, average excess deaths related to non-optimal temperatures stood at around 74/100,000 between 2000 and 2019: https://www.thelancet.com/journals/lanplh/article/PIIS2542-5196(21)00081-4/fulltext#seccestitle120

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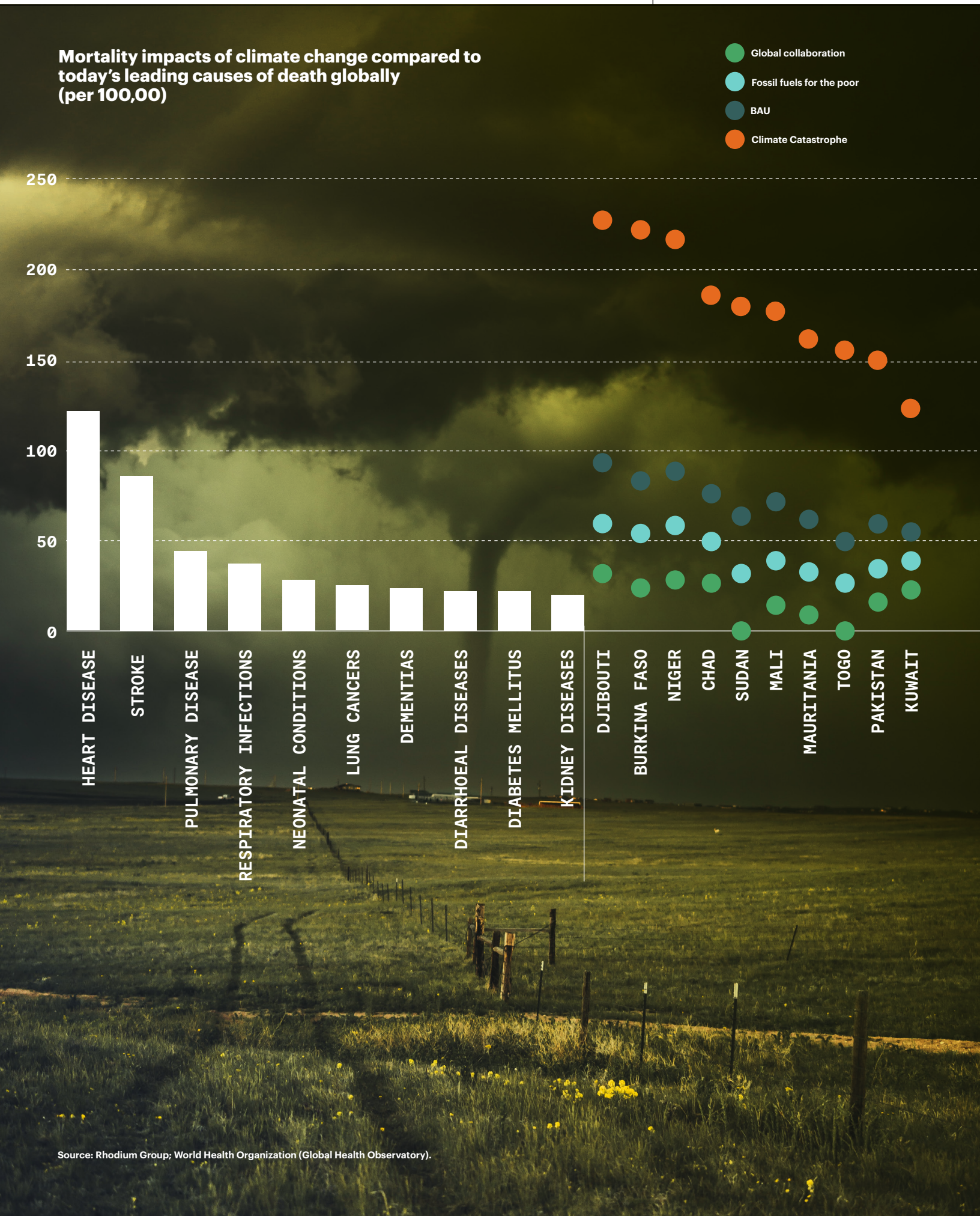


Source: Rhodium Group; World Health Organization (Global Health Observatory).

Impacts of excess heat on energy consumption

One of the vagaries of climate change and its impacts is that the countries that account for the bulk of historical greenhouse gas emissions through their industrialization, have, on average, far cooler climates than the world's developing and emerging economies. As warming accelerates, different regions are impacted in starkly different ways. In colder countries like Canada, where demand for heat can account for up to two-thirds of energy demand in buildings, the increased number of heating degree days[9] contributes to a meaningful decrease in electricity demand (implying a net economic benefit).

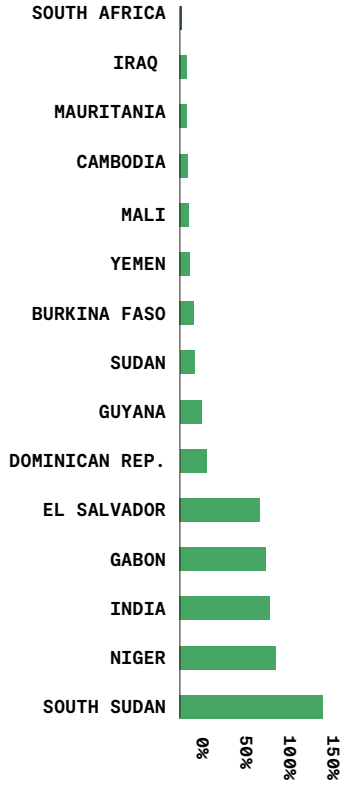
More than half of the world's developed economies (22 of 38) see a decrease in electricity demand in a global collaboration scenario as the diminished demand in the winter months more than offsets increased demand for cooling in the warmer months. Even in the country that is most severely impacted by warming in this cohort, Israel, the annual average per capita increase in electricity demand by 2090 in the Global Collaboration Scenario amounts to just 2% of current consumption today (rising to a 7% increase in the Climate Catastrophe Scenario).

The impacts on the energy-poor countries will be far more malign. Even in a world where concerted climate action limits warming to below 2 degrees Celsius, all but 10 will see increased demand for electricity linked to cooling. The extent of the increase will naturally align with the warming in each scenario, ranging from around 45 kWh/person in 2090 in the Global Collaboration Scenario, to 61 kWh/person in the Fossil Fuels for the Poor Scenario; 78 kWh/person in Business as Usual and 141 kWh/person in Climate Catastrophe. These changes, at the aggregate level, may appear modest, however, taken as a proportion of current demand in some of the most afflicted (and energy-poor countries), they could represent a growth that is an order of magnitude greater than current per capita demand. In South Sudan, for instance, the rise in electricity demand in the Climate Catastrophe Scenario amounts to over four-times the current per capita demand. This is in stark contrast to demand in the developed economies which, even in the worst-case scenario, is limited to just 0.4% of current per capita demand.

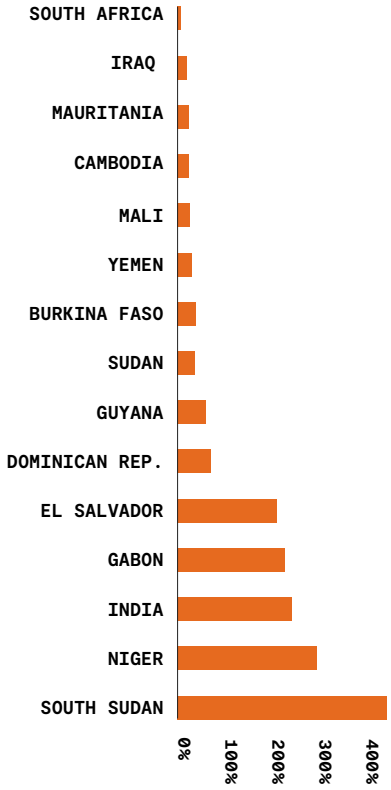
9 Heating degree-days refer to a measurement used to quantify the demand for energy needed to heat a building, taking into consideration outside air temperature.

Additional electricity demand as a proportion of current per capita demand in select countries, 2090

Global Collaboration Scenario

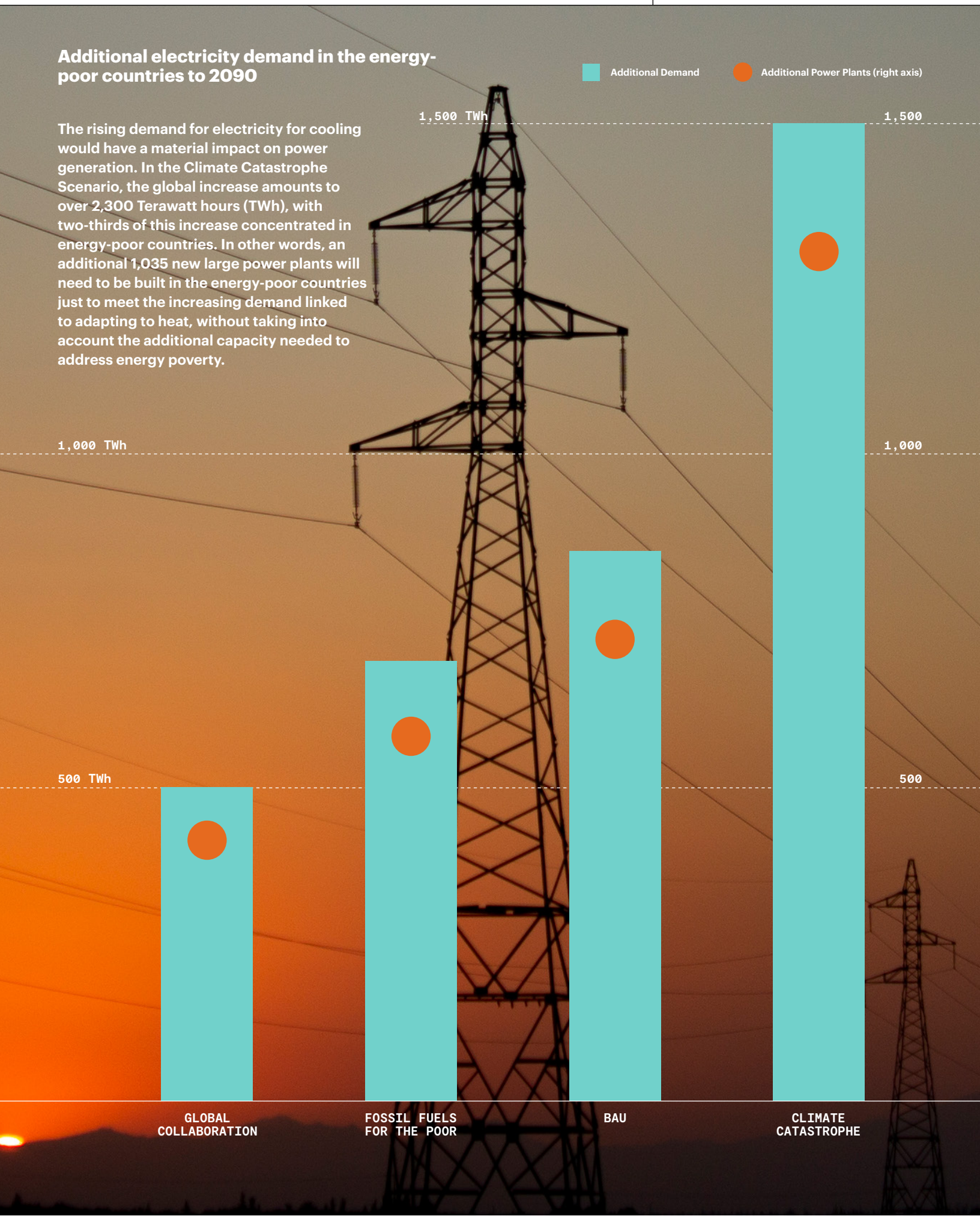


Climate Catastrophe Scenario



Additional electricity demand in the energy-poor countries to 2090

The rising demand for electricity for cooling would have a material impact on power generation. In the Climate Catastrophe Scenario, the global increase amounts to over 2,300 Terawatt hours (TWh), with two-thirds of this increase concentrated in energy-poor countries. In other words, an additional 1,035 new large power plants will need to be built in the energy-poor countries just to meet the increasing demand linked to adapting to heat, without taking into account the additional capacity needed to address energy poverty.



Conclusions

No successful path to confront climate change can overlook the needs, vulnerabilities, and exposure of the world's energy-poor countries. The world can keep global warming under acceptable limits this century, but the strategy to do so requires global cooperation to support a boom in renewables in the 81 countries now lacking reliable power. A future in which the world's least developed countries modernize using power derived from fossil fuels, even as all other countries move to decarbonize, would push global temperatures to unacceptable levels.

Put succinctly, the only successful way forward on climate mitigation requires all regions and countries to work together. There is no workable "go it alone" strategy for any one region or bloc of countries.

For humans living on a hotter planet, exposure to the most negative impacts of climate change will be determined by where you live and by global patterns of economic inequality. Those impacts—from diminished harvests of basic crops to heightened mortality due to heat—will fall overwhelmingly on the very countries that have contributed least to global emissions and benefited least from the economic benefits of reliable power.

On its present course, global climate action is far from sufficient to ward off increasing damage to the planet and human well-being. The world now faces the very real possibility of exceeding the 1.5°C limit on warming first laid out in the Paris Agreement in 2015. The Intergovernmental Panel on Climate Change has recently warned that we are "more likely than not" to breach that target by 2040. The path in this report that most closely resembles our current trajectory, Business As Usual, would result in at least 2.8 degrees of warming globally, with widespread deleterious effects.

This report vividly illustrates another IPCC contention: that "every increment of global warming will intensify multiple and concurrent hazards"[10]. The lens provided by this report's four scenarios starkly illustrates those incremental differences and the disparate impacts region by region, country by country.

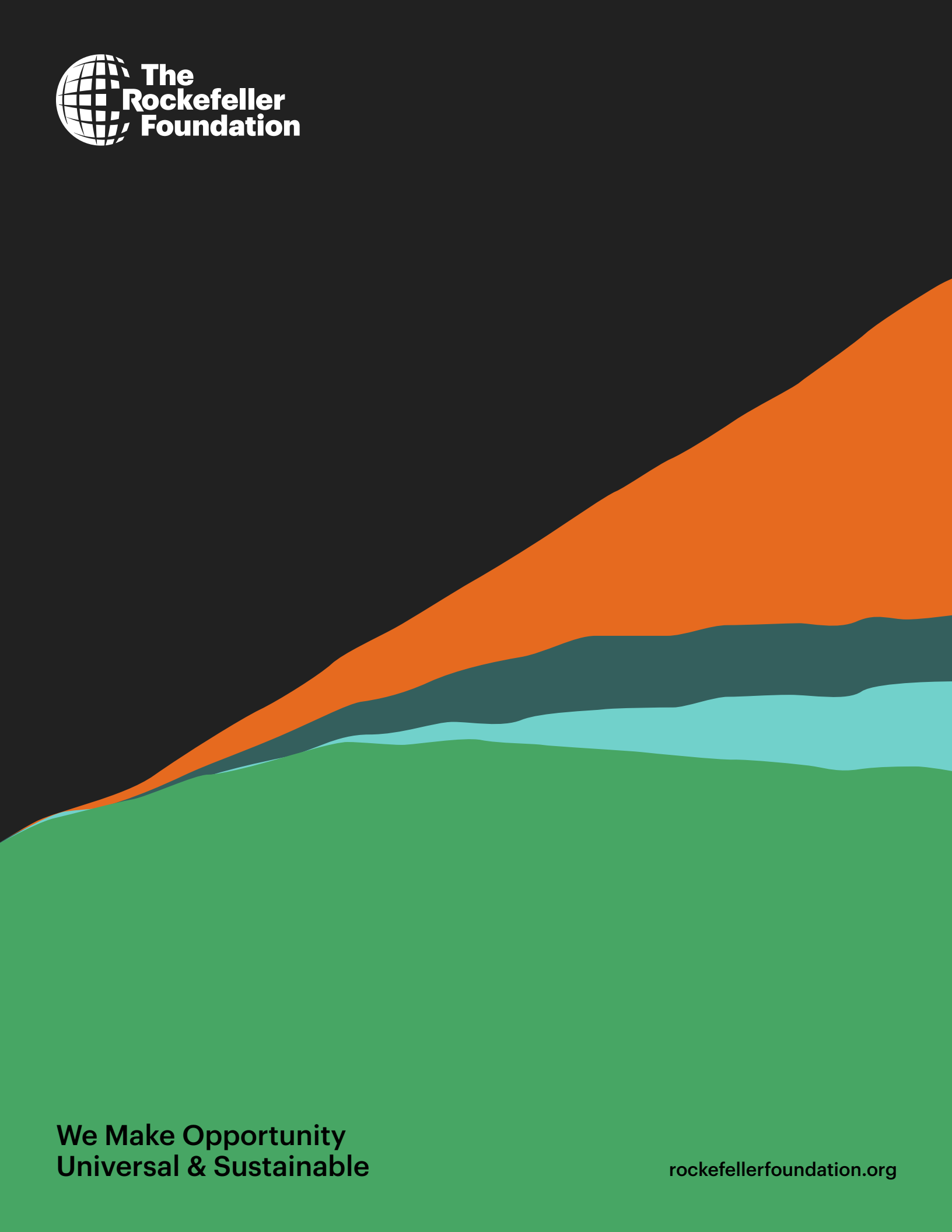
Even under the most optimistic scenario, the burden of climate change as measured by nutrition, health, and energy use will fall disproportionately on the world's poorest, while under any scenario the richer countries will remain the most resilient and the most capable of adaptation.

The impacts of a warming climate endanger development gains made across food, health, equity. The uneven and localized nature of climate change's impacts on society become pronounced within 30 years and these differences increase over time. How heavy a toll they take, particularly on those populations who are least responsible for changing the climate, depends heavily on how quickly and broadly clean energy development expands in coming decades. How energy-poor countries develop will a play major role in which trajectory or scenario most closely mirrors the reality.

To avert the most negative outcomes, we must therefore not only focus our mitigation efforts on the largest emitters of today, but also ensure that low-carbon technologies diffuse to low-income energy-poor countries to support clean development. Doing so would simultaneously mitigate climate change, while also bolstering the ability of developing countries to adapt to residual increases in temperature.

Global collaboration is not just a matter of moral imperative, but also in the interest of all countries around the world. Due to limitations of even the most cutting-edge analytical methods, the risks presented in this study are by necessity considered in silos, diminishing their likely impact. The reality will be far more complex and dire, with drought, famine, and extreme weather events increasing the likelihood of massive dislocations that could have a multitude of knock-on impacts, including in the industrialized economies. The Climate Catastrophe Scenario would all but certainly usher in a cascading series of catastrophes, each of which would amplify the other.

10 IPCC, Synthesis Report of the IPCC Sixth Assessment Report (AR6) Summary for Policymakers: https://report.ipcc.ch/ar6syr/pdf/IPCC_AR6_SYR_SPM.pdf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