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Staying Cool as the Climate Warms

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The recently released report by the Intergovernmental Panel on Climate Change (IPCC) (2021) makes depressing reading.[1] The speed at which the earth is warming has accelerated; scientists doubt that current national commitments and efforts will suffice to meet the Paris Agreement's goal;[2] and the increasing threats from tipping points such as the release of methane triggered by melting permafrost in northern latitudes[3] could result in temperatures spiking well above 1.5°C compared with preindustrial levels possibly within a decade or two.[4]

AN OVERHEATING PLANET

One manifestation of this steepening trend—and there are several that ought to focus the minds of participants at the 26th UN Climate Change Conference (COP26) in November this year[5]—is the increasing frequency, magnitude, spatial extent, and duration of heat waves.[6] They are also arriving earlier in the summer. What used to be events that occurred once every few decades in lower latitudes are turning into annual events of worsening severity. Moreover, prolonged high temperatures caused by heat domes[7] are beginning to strike regions in higher latitudes that have not experienced such

1 https://www.ipcc.ch/site/assets/uploads/2021/08/IPCC_WGI-AR6-Press-Release_en.pdf

2 https://unfccc.int/news/climate-commitments-not-on-track-to-meet-paris-agreement-goals-as-ndc-synthesis-report-is-published

3 This will be the work of microbes activated in the boggy soil. Nature (2021) https://www.nature.com/articles/d41586-021-00659-y; Nature (2019) https://www.nature.com/articles/d41586-019-01313-4

4 The average temperature is already about 1.2°C warmer than it was in 1850 and surprisingly, the sharp COVID- induced reduction in economic activity during 2020 did not lead to a temporary pause in the rising concentration of GHGs in the atmosphere. In fact, the concentration rose by 2.6 ppm to 412.5ppm or 414.4ppm as measured by the Mauna Loa Observatory. https://research.noaa.gov/article/ArtMID/587/ArticleID/2742/Despite-pandemic-shutdowns-carbon-dioxide-and-methane-surged-in-2020; https://www.ft.com/content/7b701cd2-8dc8-45b0-983d-8a20daa71932; https://www.ft.com/content/8b33177e-e17f-4668-b3a0-5554af8c8293

5 UN Climate Change Conference of Parties. https://ukcop26.org

6 S.E. Perkins-Kirkpatrick and S.C. Lewis (2020) Increasing trends in regional heatwaves. https://www.nature.com/articles/s41467-020-16970-7; https://www.ipcc.ch/site/assets/uploads/2021/08/IPCC_WGI-AR6-Press-Release_en.pdf; The IPCC report states," hot extremes (including heatwaves) have become more frequent and more intense across most land regions since the 1950s, while cold extremes (including cold waves) have become less frequent and less severe …. Some recent hot extremes observed over the past decade would have been *extremely unlikely* to occur without human influence on the climate system." https://www.ipcc.ch/report/ar6/wg1/downloads/report/IPCC_AR6_WGI_SPM.pdf . Severe weather during the first half of 2021 alone has been costly for the insurance industry, which is expecting to service claims amounting to $40 billion. Financial Times (August 13th, 2021) Spate of catastrophic weather events. https://www.ft.com/content/1053aebb-474f-4f35-9034-2475272404e1

7 When rising hot humid air is trapped under a high-pressure cap it creates a sweltering stationary heat dome, which pushes out cooler air and clouds. https://oceanservice.noaa.gov/facts/heat-dome.html; https://www.vox.com/22538401/heat-wave-record-temperature-extreme-climate-change-drought

temperatures over the period for which records are available. In the Pacific Northwest, where temperatures during June are usually in the low 20s°C, have risen to 44°C and higher this year.[8] These heat waves have sparked destructive forest fires.[9] Fires are also raging in the Amazon, Lebanon, and Greece, and in places that have rarely experienced such conflagrations.[10] The town of Verkhoyansk in the Artic Circle in Siberia recorded a temperature of 38°C on June 20, 2020, and high temperatures across Northern Siberia have resulted in destructive blazes, with over 10 million acres of forest obliterated in the Yakutia region.[11] Smoke from these fires has spread as far as the North Pole. A worrying development noted by Ferguson (2017) is the expanding fire season.[12]

The inhabitants of Jacobabad, a town in the Pakistani province of Sindh (and Ras al Khaimah in the UAE), are enduring temperatures in excess of 50°C, which endanger the survival of humans and animals.[13] The persistence of drought in the Pacific Northwest as well as in arid regions throughout the Northern Hemisphere is exacerbating the heatwaves because the lack of soil moisture intensifies the buildup of heat.[14] The frequency of these combined drought and heat waves and their duration is creeping upward—there can be between one and three events more each year and their duration can be between 2–10 days longer.[15]

The implications of this trend are dire. Higher temperatures will further impact human morbidity,[16] mortality,[17] and productivity.[18] Deaths caused by climate change-induced heat waves are on the rise.[19] The heat wave that swept through the Pacific Northwest in June 2021 has caused hundreds of fatalities

8 WSJ (2021) https://www.wsj.com/articles/record-setting-heat-wave-engulfs-pacific-northwest-11624832021

9 A report by the World Weather Attribution states that temperatures in the Pacific Northwest were 2°C hotter than they would have been if the event had occurred prior to the Industrial Revolution when the global mean temperature was lower by 1.2°C. Were global mean temperatures to rise by another 0.8°C, such an event would raise temperatures by 3°C. Such an event, which in a cooler world would happen once every 1,000 years could recur once every 5–10 years in a world where global mean temperatures exceed preindustrial levels by 2°C. S.Y. Philip et al (2021) World Weather Attribution. https://www.worldweatherattribution.org/wp-content/uploads/NW-US-extreme-heat-2021-scientific-report-WWA.pdf

10 https://www.cnn.com/2021/07/22/world/wildfires-siberia-us-canada-climate-intl/index.html

11 In an editorial published in August 2018, the Economist (London) warned that "The earth is smoldering from Seattle to Siberia" The wildfires sweeping through California were already among the worst in the state's history. https://www.economist.com/weeklyedition/2018-08-04; https://www.nationalgeographic.com/science/article/what-100-degree-day-siberia-means-climate-change; https://earthobservatory.nasa.gov/images/146879/heat-and-fire-scorches-siberia; WSJ (2021) https://www.wsj.com/articles/one-of-the-coldest-places-on-earth-is-on-fire-11628251666; By injecting black carbon into the atmosphere, wildfires contribute to warming as the carbon absorbs heat.

12 G. Ferguson (2017). *Land on Fire*. Timber Press.

13 https://www.the-sun.com/news/3176259/pakistan-city-hottest-earth-52c-no-air-con/; https://www.telegraph.co.uk/global-health/climate-and-people/hotter-human-body-can-handle-pakistan-city-broils-worlds-highest/

14 K. Whan et al. (2015) Impact of soil moisture. https://www.sciencedirect.com/science/article/pii/S2212094715000201; https://research.noaa.gov/article/ArtMID/587/ArticleID/2472/Climate-change-to-make-hot-droughts-hotter-in-the-US-southern-plains

15 https://eos.org/articles/simultaneous-drought-and-heat-wave-events-are-becoming-more-common

16 The elderly, young children, the obese and those on diuretics are at greatest risk—a sizable percentage of the total population in developing countries and developed ones.

17 Ahima (2020) underscores the severity of the threat to humans at high temperatures. "Extreme deviations from the normal core temperature, i.e., a dip below 27°C (hypothermia) or an increase above 42°C (hyperthermia) can be fatal. Extreme heat spurred by global warming poses an existential threat to human populations." https://dm5migu4zj3pb.cloudfront.net/manuscripts/135000/135006/cache/135006.2-20200131134529-covered-253bed37ca4c1ab43d105aefdf7b5536.pdf

18 Hospital admissions or death can result from dehydration, heat strokes, and complications associated with cardiovascular disease, respiratory disease, acute renal failure, and mental illness.

19 https://www.newscientist.com/article/2278919-climate-change-to-blame-for-37-per-cent-of-worlds-heat-related-deaths/

in Oregon and British Columbia.[20] In 2003, a prolonged heatwave affecting Western and Southern Europe was responsible for 70,000 excess deaths,[21] and a heatwave that struck Chicago on July 13, 1995, resulted in the death of over 700 city residents, mostly those who were elderly or poor.[22] Almost 125 people died in Japan when temperatures in Tokyo soared above 40°C for the first time in 2018.[23]

Spiking temperatures will imperil the integrity of transport (buckling of roads, warping of railway tracks)[24] and energy infrastructures (electrical grid) and the supply of fresh water for farming, industry, power generation, and human consumption will be sharply constrained in several regions, many currently suffering from water scarcity. City dwellers, already the majority of the world's population and likely to exceed two-thirds of the total by mid-century, will be exposed to higher temperatures because the congested, built-up urban environment traps heat and experiences temperatures several degrees higher than the countryside. For those living in the tropical belt and others at higher latitudes now subject to temperature extremes of longer duration, adapting to higher temperatures can no longer be postponed. If human productivity goes south, decades of hard-won gains in the quality of life will melt away.

The oceans have not escaped. Not only is the temperature and acidity of the oceans on the rise but also, marine heatwaves are becoming more frequent, with deleterious ripple effects across the marine food chain. Moreover, these heatwaves are destroying coral reefs, which, in turn, damages coastal fisheries.[25] For many communities dependent on artisanal fishing for their livelihoods and food supply, this would be a severe blow.

The imminent threat recalls views recently expressed by Martin Rees (2020):[26]

> The climate crisis … is in effect, a slow-motion version of COVID [crisis]…we need to start preparing …. If you were alive in the Middle Ages, the era when they built the cathedrals, it was miserable, but there wasn't very much that could be done to make it better. There wasn't the scientific knowledge. Whereas now we are better off, but the gap between the way the world is and the way it could be is wider than in medieval times …. It may seem ironic that [in medieval

20 https://www.oregonlive.com/weather/2021/07/death-toll-from-historic-heat-waves-rises-to-107.html; https://www.bbc.com/news/world-us-canada-57654133; https://www.nationalgeographic.com/environment/article/heat-related-deaths-attributed-to-climate-change

21 According to Gabriel and Endlicher (2010) experience from the United States indicates that heatwaves can cause much greater loss of lives than blizzards, cyclones, and floods. http://www.theurbanclimatologist.com/uploads/4/4/2/5/44250401/urbanruralmortality.pdf; J.M. Robine et al. (2008) https://www.sciencedirect.com/science/article/pii/S1631069107003770; D. Mitchell et al. (2019) https://www.thelancet.com/journals/lanplh/article/PIIS2542-5196(19)30106-8/fulltext

22 The low-income households are usually concentrated in parts of the city, which are most congested and lacking in tree cover or green spaces and where the heat island effect is most acute. (Nature 2021) https://www.nature.com/articles/d41586-021-01881-4; https://www.scientificamerican.com/article/chicago-learned-climate-lessons-from-its-deadly-1995-heat-wave1/; E. Klineberg (2015) *Heat Wave*. University of Chicago Press. Observes that death rates were highest in areas largely abandoned by services providers, where social capital had withered and where many (particularly men) lived in isolation in single room occupancy dwellings.

23 https://english.kyodonews.net/news/2018/08/2f9ba81a3d3f-temperature-climbs-above-40-c-again-as-japan-heat-wave-continues.html?phrase=aso&words=

24 https://www.sydney.edu.au/news-opinion/news/2019/11/27/how-climate-change-impacts-infrastructure--experts-explain.html

25 https://www.nature.com/articles/d41586-021-01142-4

26 https://thebulletin.org/premium/2020-12/buckle-up-we-are-in-for-a-bumpy-ride-an-interview-with-royal-astronomer-martin-rees/

> times] they built cathedrals that wouldn't be finished in their lifetime even though their horizons then in space and time were very limited. They thought that their grandchildren would admire the finished cathedral, even if they didn't live to see it. Whereas now we don't plan so much ahead despite the fact that we've got huge cosmic horizons and longer human lifespans.

We have the scientific knowledge; we could limit warming and enable future generations to enjoy a quality of life equal to or better than our own. But for years, in the face of an outpouring of scientific evidence on the changing climate, the global community has fiddled as the earth slowly burns.[27] And now because of denial, shortsightedness, and selfish disregard for the fate of future generations, time is not just running short, it is running out. Technological optimism must prevail over political obduracy.

Climate change demands determined efforts to contain greenhouse gas (GHG) emissions. That is the foremost priority. In addition, because controlling emissions even under the most optimistic scenarios will take decades and the carbon released will remain in the atmosphere for thousands of years, some increase in warming is already baked in.[28] Hence, adapting to higher temperatures will be a necessity. The balance of this note examines why such adaptation will be sorely needed in order to preserve and extend economic gains, and the policy measures as well as the technologies that will enable us to stay cool and keep our cool.

IMPAIRED PRODUCTIVITY, GDP LOSSES, AND WORSENING INEQUALITY

Research shows that labor productivity peaks at 13°C and with rising workplace temperatures, it first plateaus and then declines by 2 percent per degree increase over 22°C or 25°C depending on activity (Burke et al. 2015; Hsiang 2010; Niemala 2002; Somanathan et al. 2018).[29] Temperatures of between 22°C and 24°C are a cause of heat strain or heat stress for workers and compromise work effort (Flouris et al. 2018).[30] Services output in the Caribbean falls by 6 percent for every 1°C increase in daily average temperature above 27°C–29°C (Hsiang 2010).[31] A study of auto workers in the US found that productivity was off by 8 percent when there were six or more days when the temperature rose above 32°C (Cachon et al 2013).[32] Deryugina and Hsiang (2014)[33] find that labor productivity in the United States slips by 1.7 percent for every 1°C increase in average temperature above 15°C, with a 0.06–0.16 percent annual erosion of GDP. Elevated nighttime temperatures, by reducing the duration of sleep and sleep quality, impair cognitive skills and health, and can even be a cause of death. Sleep quality deteriorates once temperatures rise above 32°C and warming elevates the incidence of violent crime

27 The inability of the G20 in July 2021 to agree to the phasing out of coal is emblematic of the foot-dragging that has been ongoing for decades. https://www.reuters.com/world/g20-loath-commit-climate-meeting-tussle-over-carbon-wording-2021-07-23/

28 https://www.ipcc.ch/report/ar6/wg1/downloads/report/IPCC_AR6_WGI_SPM.pdf

29 https://www.washingtonpost.com/news/energy-environment/wp/2016/07/19/as-the-world-grows-hotter-some-workers-are-becoming-less-productive/; Burke et al. (2015) https://web.stanford.edu/~mburke/climate/BurkeHsiangMiguel2015.pdf; Niemala et al. (2002) studied call center workers in India; Somanathan et al. (2018) assessed the productivity of workers in the cloth weaving, and garments industries and workers producing steel for infrastructure building. http://www.regionalclimate-perspectives.com/uploads/4/4/2/5/44250401/niemalaetal2002callcenterproductivity.pdf; https://bfi.uchicago.edu/wp-content/uploads/BFI-WP_2018-69.pdf

30 Flouris et al. (2018) Lancet. https://www.thelancet.com/journals/lanplh/article/PIIS2542-5196(18)30237-7/fulltext

31 S.M. Hsiang (2010) Temperatures and cyclones strongly associated with production in the Caribbean and Central America. https://www.pnas.org/content/107/35/15367.full; https://www.washingtonpost.com/news/wonk/wp/2012/09/24/a-hotter-world-is-a-less-productive-world/

32 https://www.researchgate.net/publication/256023169_Severe_Weather_and_Automobile_Assembly_Productivity

33 https://www.nber.org/papers/w20750

and of suicides (Zheng et al. 2019; Burke et al 2018; Ranson 2014).[34] 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 (Dell et al. 2012).[35] According to the US Global Change Research Program, (2018, p.41)[36] under a high warming scenario, close to 2 billion hours of labor would be lost annually in outdoor sectors such as agriculture and construction because of the harm to labor productivity and the health of workers. The increasing spread of vector borne disease will be an additional hazard.[37]

Moreover, by eroding labor productivity, rising temperatures quickly register on the GDP bottom line: each degree increase over the annual average can over time shave between 2–3 percent off the per capita GDP (Park and Heal 2013; Dell et al. 2013).[38] Burke and Tanatama (2019)[39] conclude from their calculation using data from 11,000 counties across 37 countries that rising temperatures since 2000 had inflicted losses on the US and the EU amounting to $4 trillion and that warming had trimmed 5 percent of the GDP of developing economies. Kalibata and Skierka (2021)[40] estimate that because of higher temperatures, Africa is already losing about 1.4 percent of GDP annually and adaptation costs are running as high as 3 percent of GDP. Kahn et al. (2019)[41] project a 7.22 percent reduction in global per capita GDP by 2100 if average temperatures continue rising by 0.04C each year. Their research on 48 US states between 1963 and 2016 points to long-lasting damage from rising temperatures to output (including agricultural production, which is especially sensitive to climate),[42] productivity, and

34 https://www.ncbi.nlm.nih.gov/pmc/articles/PMC6351950/pdf/ijerph-16-00270.pdf; Hafner et al. (2017) https://www.ncbi.nlm.nih.gov/pmc/articles/PMC5627640/; M. Burke et al (2018) Higher temperatures increase suicide rates in the US and Mexico. https://www.nature.com/articles/s41558-018-0222-x; M. Ranson (2012) Crime weather and climate change. https://www.hks.harvard.edu/centers/mrcbg/publications/awp/awp8

35 https://www.aeaweb.org/articles?id=10.1257/mac.4.3.66

36 United States Global Change Research Program (2018). *The Climate Report*. Melville House Publishing.

37 J. Rocklov and R. Dubrow (2020) Climate change: An enduring challenge for vector borne disease prevention and control. https://www.nature.com/articles/s41590-020-0648-y. Warming will affect the transmission of disease through multiple pathways by affecting "the pathogen, the vector, non-human hosts and humans. Because arthropods and other vectors are ectotherms, it is expected that vector abundance, survival and feeding activity will increase with increasing temperature, as will the rate of development of the pathogen within the vector."

38 https://www.nber.org/papers/w19725; https://www.nber.org/papers/w19578; "Excessive heat during work creates occupational health risks; it restricts a worker's physical functions and capabilities, work capacity and productivity. Temperatures above 24–26°C are associated with reduced labor productivity. At 33–34°C, a worker operating at moderate work intensity loses 50 per cent of his or her work capacity. Human physiological limits are breached once wet bulb temperatures reach or exceed 35 degrees Celsius. Projections based on a global temperature rise of 1.5°C by the end of the twenty-first century, and on labor force trends, suggest that, in 2030, 2.2 per cent of total working hours worldwide will be lost to high temperatures—a productivity loss equivalent to 80 million full-time jobs. This is, however, a conservative estimate. Agricultural and construction workers are expected to be the worst affected. The agricultural sector alone accounted for 83 per cent of global working hours lost to heat stress in 1995 and is projected to account for 60 per cent of such loss in 2030. Further, temperature rises will make some agricultural areas unproductive, displacing many workers. Whereas construction accounted for just 6 per cent of global working hours lost to heat stress in 1995, this share is expected to increase to 19 per cent by 2030." ILO (2019) https://www.ilo.org/wcmsp5/groups/public/---dgreports/---dcomm/---publ/documents/publication/wcms_711919.pdf; https://advances.sciencemag.org/content/6/19/eaaw1838

39 https://www.nber.org/papers/w25779

40 A. Kalibata and K. Skierka (2021) Powering sustainable food systems. https://www.project-syndicate.org/commentary/climate-food-systems-summit-helping-smallholder-farmers-by-agnes-kalibata-and-kristina-skierka-2021-04?barrier=accesspaylog

41 https://www.nber.org/papers/w26167

42 The hot dry weather during late spring and the summer of 2021 strongly impacted the condition of the spring wheat crop in the United States and Russia. Grain harvest forecasts were trimmed for the 2021–2022 season by the International Grains Council. Wall St. Journal (August 23rd, 2021) crops wither under scorching heat. https://www.wsj.com/articles/u-s-crops-wither-under-scorching-heat-11629797401

employment. The damage according to Burke et al. (2015)[43] could be even higher if there is no tapering of current trends in rate of warming. They estimate that average global per capita incomes will be 23 percent lower by 2100 relative to scenarios without global warming. Warming will also lead to widening inequality within and between nations (Diffenbaugh and Burke 2019).[44] Ignoring the upward creep of the mercury will only serve to tip developing countries into increasingly precarious economic circumstances—and developed countries will also not escape unscathed either.

Inevitably, it is the poor who suffer the most because they tend to be concentrated in the most heat-prone areas within countries and cities and because they are engaged in activities that expose them to higher temperatures (agriculture, transport, refuse collection, construction, manual work). Intra-country inequality has been on the rise in many emerging markets and developing economies and warming appears to be exacerbating this trend because of the (i) exposure of low-income groups to climate change; (ii) greater susceptibility of this income group to the damage from climate change; and (iii) climate change diminishes their ability to cope and recover.[45] Diffenbaugh and Burke (2019)[46] estimate that the gap "between the top and bottom population-weighted deciles has become 25 percent larger (5th to 95th range of −6 percent to +114 percent) during the 1961–2010 period compared with a world without global warming, with ~90 percent likelihood that the ratio has increased. Likewise, the ratio between the top and bottom population-weighted quintiles has become 45 percent larger (5th to 95th range of +10 percent to +99 percent), with ~99 percent likelihood that the ratio has increased."

STAYING COOL: TECHNOLOGY TO THE RESCUE?

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 in urban areas where heat island effects can exacerbate the warming induced by climate change.[47] Air conditioning[48] on a broad scale—as in Singapore and in the Emirates[49]—is a solution, but it is a costly, energy-intensive solution, which is currently (and for the foreseeable future) beyond the reach of most of the population in developing countries (Zivin and Kahn 2016).[50] The Singapore economic "miracle" would have been inconceivable without widely available air-conditioning. Lee Kuan Yew (2009)[51] maintained that "air conditioning was a most important invention for us, perhaps one of the signal inventions of history. It changed the nature of civilization by making development possible in the tropics. Without air conditioning you can work only in the cool early-morning hours or at dusk. The first thing I did upon becoming prime minister was to install air conditioners in buildings

43 https://web.stanford.edu/~mburke/climate/BurkeHsiangMiguel2015.pdf

44 https://www.pnas.org/content/116/20/9808

45 S.N. Islam and J. Winkel (2017) Climate change and social inequality. https://www.un.org/esa/desa/papers/2017/wp152_2017.pdf

46 N.S. Diffenbaugh and M. Burke (2019) Global warming has increased global inequality. PNAS. https://www.pnas.org/content/116/20/9808

47 C. Harvey (2019) https://www.scientificamerican.com/article/urban-heat-islands-mean-warming-will-be-worse-in-cities/

48 Modern air-conditioning technology was patented by Willis Carrier in 1906 based on a design he introduced in 1902. Previously, the techniques to cool homes, workplaces, recreational halls, and 'reefers' used ice, manually operated devices (Benjamin Franklin was the co-inventor of one) and in the late nineteenth century, steam driven contraptions. The small window units suitable for use in homes first appeared in 1938. S. Basile (2014) *Cool: How Air Conditioning Changed Everything*. Fordham University Press.

49 https://www.washingtonpost.com/graphics/2019/world/climate-environment/climate-change-qatar-air-conditioning-outdoors/; https://www.cnn.com/2014/01/02/world/meast/dubai-can-wind-power-take-the-heat/index.html

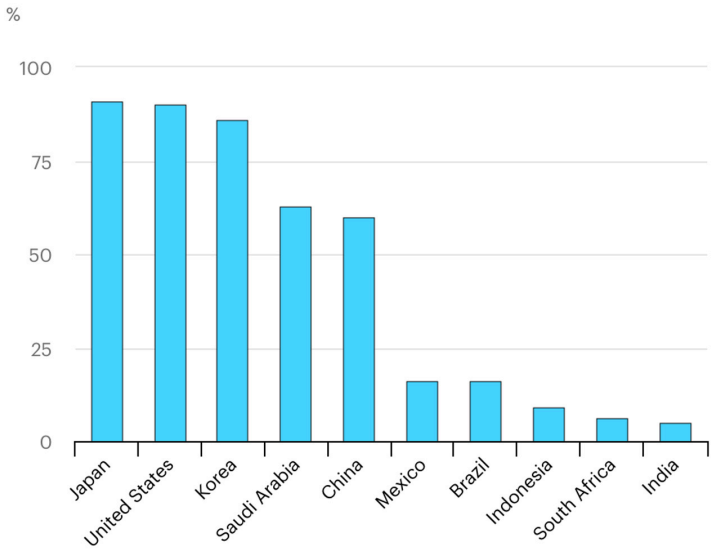
50 https://www.nber.org/papers/w22962

51 https://www.vox.com/2015/3/23/8278085/singapore-lee-kuan-yew-air-conditioning

where the civil service worked. This was key to public efficiency." Widespread adoption of affordable cooling techniques with minimal increase in carbon emissions requires advances in technology (passive and other), the design of urban spaces, and electricity from renewable sources.

The use of air-conditioning or fans consumed about a fifth of all electricity worldwide in 2018. The demand for space cooling could increase threefold by 2050 as the global population, urbanization and temperatures increase, incomes rise and more people in developing countries can afford to install cooling systems of varying degrees of efficiency (Figures 1&2).[52] By the middle of the century all the devices in use combined could account for 37 percent of the electricity consumed worldwide resulting in what the IEA calls an impending "cold crunch."[53]

Figure 1. Percentage of households with A/C in 2018



Source: IEA (2018) The future of cooling. https://www.iea.org/reports/the-future-of-cooling

The use of air-conditioning on such a massive scale could add half of a degree Celsius to the warming trend because of the increased demand for electricity and through the release of refrigerants, which are potent GHGs.[54] In Khosla's words (2020),[55] "This increased electricity demand risks locking the world into a feedback loop, where demand for cooling energy drives further greenhouse gas emissions and results in even more global warming—necessitating further cooling."[56]

However, active and passive technologies backed by desirable regulations/standards, pricing strategies and investment in a smart grid could bring temperature management on a large scale within

52 L. Davis and P. Gertler (2015) Contribution of air conditioning. PNAS. https://www.pnas.org/content/112/19/5962; Lee Kuan Yew believed that air-conditioning was a more significant invention than the printing press and the steam engine. With Singapore heating by 0.25°C per decade, A/C has become a necessity with 80 percent of households owning a unit in 2020. Just 8 percent of Indian households have air-conditioning (mostly window units) and the Indian government forecasts that by 2026, more than a fifth of all households will have installed a unit. J. Vasagar (2021) *Lion City: Singapore and the Invention of Modern Asia*. Little Brown.

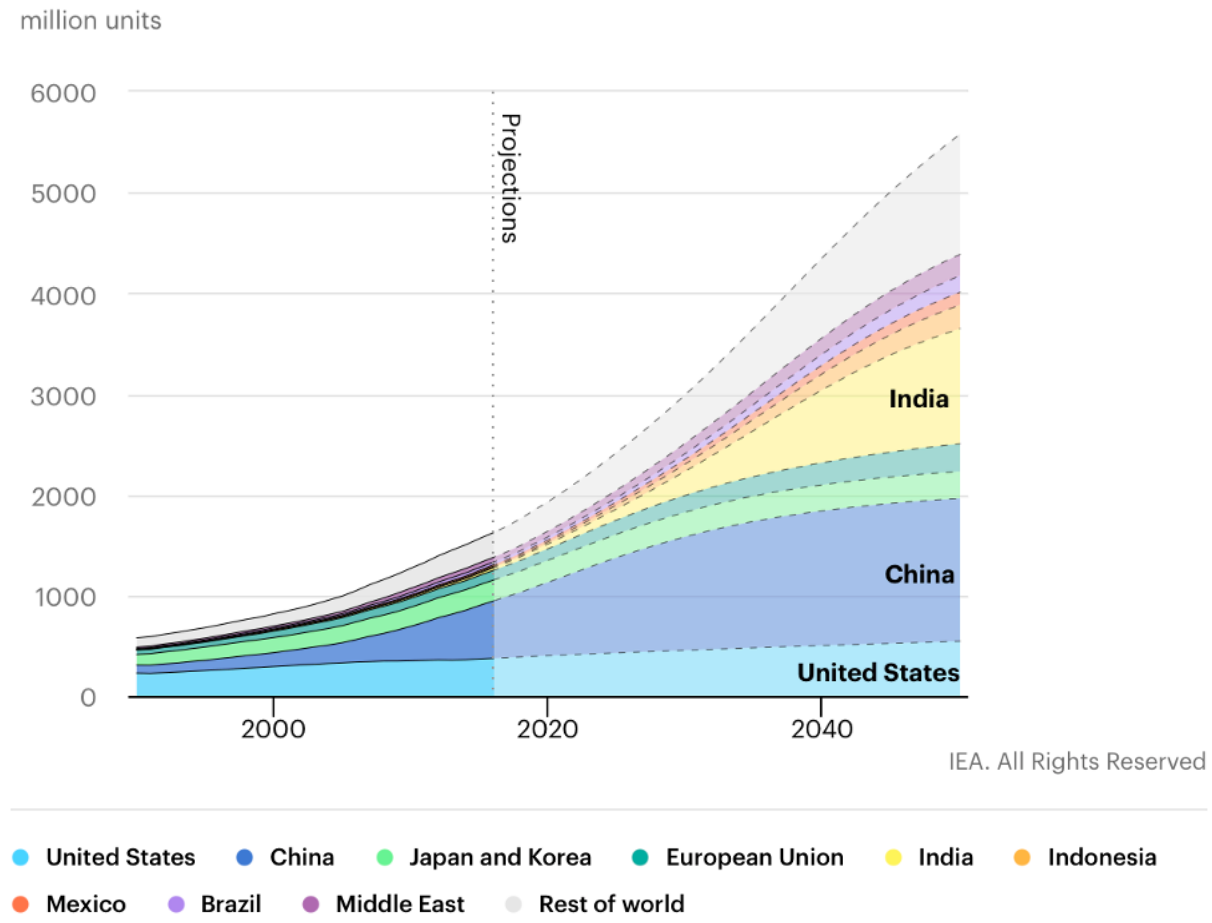
53 https://www.weforum.org/agenda/2020/01/these-innovations-could-keep-us-cool-without-heating-us-up/

54 https://yaleclimateconnections.org/2019/06/rising-demand-for-air-conditioning-could-make-climate-change-even-worse/

55 R. Khosla (2020) Demand for cooling. WEF. https://www.weforum.org/agenda/2020/10/cooling-energy-use-electricity-climate-change-heat-waves-sustainability

56 Temple (2020) observes: "Air conditioning represents one of the most insidious challenges of climate change, and one of the most difficult technological problems to fix. The more the world warms, the more we'll need cooling … But air conditioners themselves produce enough heat to measurably boost urban temperatures, and they leak out highly potent greenhouse gases too. Plus, those billions of energy-hungry new units will create one of the largest sources of rising electricity demand around the world. Without major improvements, energy demand from cooling will also triple, reaching 6,200 terawatt-hours by 2050." https://www.technologyreview.com/2020/09/01/1007762/air-conditioning-grid-blackouts-california-climate-change/?truid=29925f14149c20b694d87948fbd9aa0b&utm_source=the_download&utm_medium=email&utm_campaign=the_download.unpaid.engagement&utm_term=non-subs&utm_content=09-01-2020

Figure 2. Stock of global A/C units 1990–2050



Source: IEA (2018) The future of cooling. https://www.iea.org/reports/the-future-of-cooling

reach of low- and middle-income countries while curtailing carbon emissions.[57] There are a variety of cooling technologies currently available for example, "sorption cooling,[58] desiccant cooling, magnetic cooling, thermoacoustic cooling, thermoelectric cooling, and trans critical CO2" (Brown and Domanski 2014).[59] Developing these further and finding other less pricey options should be (and is becoming) one area of intensive research. The finalists for the Global Cooling Prize[60] have come forward with several 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

57 Widespread adoption of heat pumps could reduce carbon emissions from homes and buildings. However, heat pumps are more effective for purposes of heating and less for cooling. China is actively promoting their use with subsidies. https://spectrum.ieee.org/energywise/energy/environment/heat-pumps-could-shrink-the-carbon-footprint-of-buildings; https://www.scientificamerican.com/article/the-u-s-is-ignoring-the-climate-benefits-of-heat-pumps/

58 https://www2.jpl.nasa.gov/adv_tech/coolers/Sorption_overview.htm

59 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

60 Established in 2018.

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."[61] 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 countries. A/C units with fewer joints can reduce the leakage of refrigerants and a membrane-based rooftop unit that uses water as a refrigerant could if perfected, save on power usage.[62] Home power consumption for cooling purposes can be reduced by smart programmable controllers, ductless HVAC systems that cool a specific area integrated with zone control systems, which divide the dwelling into zones each with a dedicated thermostat.[63]

Innovation in architectural designs that incorporate passive cooling mechanisms in building also reduces energy consumption.[64] This transfers 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 roof 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 second and related area of research is on renewable energy technologies. As the electrification of the economy increases the demand for power will rise manifold following the widespread adoption of electric vehicles, and the greater use of cooling equipment. This must go hand in hand with structural change and decreased reliance on fossil fuels as well as a further substantial decline in the per Kwh cost of power from renewable sources so that green energy can supplant much of the power derived from coal in particular (Figure 3).[65]

As wind and solar begin to bulk large in the energy picture, the importance of distributed generation,[66] the use of smart grid technology and utility scale storage devices will increase, which will contribute to the robustness of the energy infrastructure.[67] This is a third area of research and innovation complementing the other two. Distributed energy systems,[68] which generate and store power close to

61 https://www.weforum.org/agenda/2020/01/these-innovations-could-keep-us-cool-without-heating-us-up/. Among the more cost-effective technologies, three are especially promising: (i) One uses a "a multi split method is used to connect three indoor units with one outdoor unit. This method helps optimize refrigerant flow rate for each of three indoor units depending on ever-changing cooling load and use refrigerant control technology to closely modulate the capacity. Second, evaporative cooling method is used to improve the system efficiency by using heat of vaporization to lower the temperature of the air that outdoor unit takes in"; (ii) a second "integrates an electro-osmotic membrane dehumidifier with a water-based direct evaporative cooling system to achieve air conditioning without using any refrigerant." And (iii) a third 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.

62 https://www.energy.gov/eere/articles/5-new-air-conditioning-technologies-keep-you-cool

63 https://www.cielowigle.com/blog/hvac-technology/

64 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).

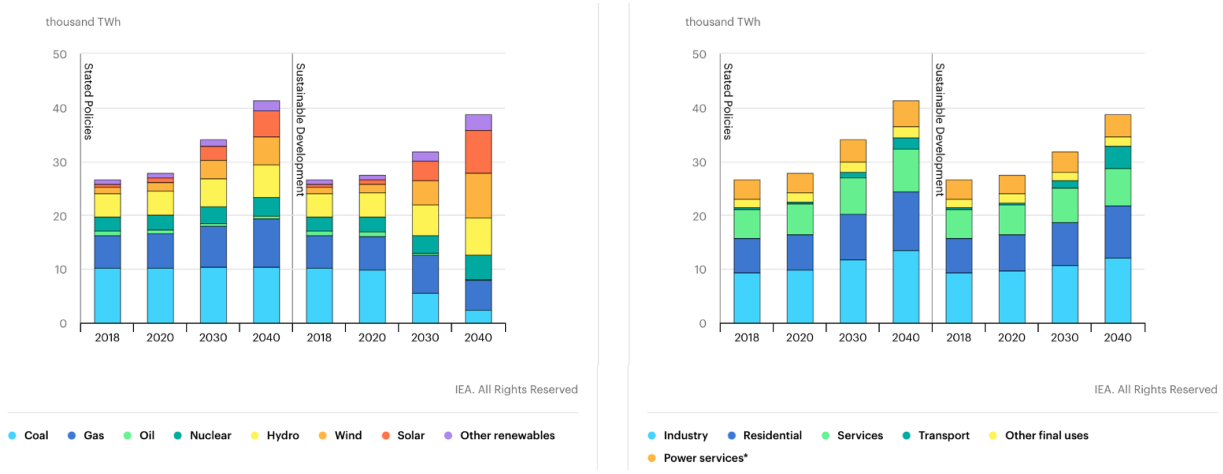
65 Some of the technological advances are briefly described in https://www.power-technology.com/comment/renewable-energy-technology-trends/

66 https://www.epa.gov/energy/distributed-generation-electricity-and-its-environmental-impacts; https://www.sciencedirect.com/topics/engineering/distributed-power-generation

67 Heal (2016). On utility level storage also see Cole and Frazier (2019); https://www.scientificamerican.com/article/utility-scale-energy-storage-will-enable-a-renewable-grid/

68 https://www.power-technology.com/comment/distributed-power-generation/

Figure 3. Electricity generation by fuel and electricity demand by sector stated policies and sustainable development



Source: IEA (2019) https://www.iea.org/reports/world-energy-outlook-2019/electricity

the consumer, have been around for over a century, but are entering a new technological epoch, and developing countries must actively participate in pushing the technology frontier and not watch from the sidelines. Behind the meter storage has grown rapidly as electricity tariffs have risen, and the cost of solar modules and storage systems has declined.[69]

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 selective 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,[70] factory production of modules,[71] which can be assembled on site using mechanized equipment, and other advances will need to be rendered cost effective and assimilated by countries where construction is still very labor intensive and relies on dated on-site 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 RD&I so that the technology can evolve and be transferred more rapidly to tropical countries where it will be needed as warming continues.

The urbanizing trend noted earlier could expose city dwellers to significantly higher temperatures because by 2100, cities could warm by 4.4°C—more than twice the global average—because of heat island effects. Even if global temperature increase is capped at 1.5°C, cities will be several degrees warmer.[72] Energy frugal cooling technologies would mitigate the problems caused by temperature extremes. In addition, changes in urban design and the use of passive measures could lessen the heat island effect

69 https://www.solarpowerworldonline.com/2019/02/behind-the-meter-energy-storage-surges-ahead-of-utility-operated-batteries/

70 https://www.businessinsider.com/3d-homes-that-take-24-hours-and-less-than-4000-to-print-2018-9

71 https://www.nytimes.com/2018/06/07/business/economy/modular-housing.html

72 https://www.nature.com/articles/d41586-021-01903-1. Summer heat was responsible for hundreds of deaths in Vancouver, Seattle, and Portland in 2021.

and urban living could be made more bearable during summer months with the help of active cooling measures. Green (or white) roofs, net zero building designs,[73] green spaces, permeable pavements and cooler, concrete pavements using reflective coating with higher albedo,[74] and the planting of trees for shade, which also reduces stormwater runoff and flooding,[75] can shave temperature peaks in urban centers. A green roof project implemented in Xiamen Island, which created 540,000 sq.m of green roofing between 2015 and 2017, reduced average land temperature by 0.91°C in 2017 as compared with 2014.[76]

CONCLUDING OBSERVATIONS: TIME TO ACT

The incidence of severe weather events may at long last be galvanizing sufficient public support in high-income countries for actions that could result in net zero carbon emissions by mid-century. Whether public opinion will compel politicians with short horizons, financial institutions and companies that prioritize profit maximization, and the many industries reliant upon fossil fuels to commit to costly policies and investments, remains to be seen. Emerging markets and developing economies invested less than $150 billion in clean energy projects in 2020.[77] Developing countries continue to equivocate and demand transfers of resources and of technology from advanced countries before they make credible commitments and follow through with implementation on scale. Rich countries dither and underdeliver on promises. While the active participation of the leading emitters such as China, the US, the EU, Japan, and Korea might perhaps be cemented by mid-decade, that of many emerging market and less developed economies such as India, Indonesia, and Brazil are far from certain. Much of the growth in GHG emissions will be from countries in Asia, Africa, and Latin America.[78] Unless they too can be brought on board, the concentration of carbon in the atmosphere will not be contained, the warming trend will continue past 2°C, and the heat waves will become fiercer.

The scientific evidence on anthropogenic warming is compelling, but many decision makers remain hesitant or unconvinced. Although delay could be potentially catastrophic and there are substantial benefits to be derived from a Big Investment Push to accelerate transition to a net zero economy, many decision makers continue to be swayed by the residual uncertainties regarding the course climate change might take,[79] the magnitude of stranded assets,[80] the cost of greening development using technologies some of which are still evolving, the likelihood that more cost effective technologies could materialize in the coming decades, and the possible loss of near-term competitiveness if rivals defer investing in measures to reduce emissions.

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73 These can use natural ventilation, dehumidification techniques, insulation, and improved construction material. K. Sudhakar et al (2019) https://www.sciencedirect.com/science/article/pii/S2214157X18304131

74 Between 30 and 45 percent of the average city area is devoted to pavement. In the depths of summer, pavement temperature can range from 48°C to 65°C and this warms the air in the daytime and continues into the night. Pavements can be made cooler with coatings and other innovations. C. Wang et al (2021) https://www.sciencedirect.com/science/article/abs/pii/S1364032121004603; https://www.epa.gov/heatislands/using-cool-pavements-reduce-heat-islands

75 https://www.epa.gov/heatislands/climate-change-and-heat-islands

76 J. Dong et al (2020) "The cooling effect was significant up to 100m from the green roof installation in Xiamen Island, we called it as characteristic cooling buffer zone. Regression analysis revealed that for every 1000 m2 increase in green roof area, the average LST of the roof and its characteristic cooling buffer zone decreased by 0.4 °C." https://www.sciencedirect.com/science/article/abs/pii/S0959652620301992?via%3Dihub

77 IEA/World Bank (2021) https://www.iea.org/news/it-s-time-to-make-clean-energy-investment-in-emerging-and-developing-economies-a-top-global-priority; https://www.reuters.com/article/us-global-energy-investment-renewables/clean-energy-investment-needed-to-avert-emissions-surge-in-developing-world-says-iea-idUSKCN2DL1WW

78 https://www.enerdata.net/publications/executive-briefing/ghg-emissions-trends-developing-countries-cop26.html

79 R.S. Pindyck (2020) What we know and don't know about climate change. https://papers.ssrn.com/sol3/papers.cfm?abstract_id=3614104

80 Stranded assets are of great concern to oil rich economies and to owners of fossil fuel intensive industrial assets.

COP 26 presents an opportunity to take bold steps. Among the many that are being debated,[81] three deserve priority:

First, the commitments and pledges by countries to arrive at net zero emissions come as *The Economist* (2021)[82] notes "in many shapes and sizes … using different benchmarks and definitions, [which] can obscure how ambitious each country plans to be." These commitments need to be standardized, with all countries hewing to a common protocol for measuring GHGs. Furthermore, a credible mechanism for enforcing pledges needs to be put in place. Carbon clubs[83]/carbon border adjustment mechanism are one possible option. Other options need to pursued. However, absent a means of enforcement, evasion, leakage, and free riding will be difficult to check.

Second, in 2009, developing countries were promised $100 billion from advanced nations to defray a part of the cost of greening their economies. Little more than one half of this amount has been made available in the form of new lending. To ensure the full participation of developing countries in measures to control climate change that emerge from COP26, OECD countries will need to commit to and deliver net climate related assistance in excess of $100 billion.[84]

Third, there is an urgent need to ramp up RD&I so as accelerate technological advances, without which no amount of policy action will suffice. Public spending on low-carbon energy research by IEA members has not increased over the past decade and the $30 billion invested in 2019 is less than the expenditure in 1980[85]—with the United States spending under $9 billion.[86] This is a fifth of the research outlay on health and defense.[87] An IEA report emphasizes the desirability of speeding up the pace of innovation, stating that "Roughly half of the reductions that the world needs to swiftly achieve net-zero emissions in the coming decades must come from technologies that have not yet reached the market today."[88] New technologies would also minimize the problem of carbon lock in. "If the right technologies in the steel, cement and chemical sectors can reach the market in time for the next 25-year refurbishment cycle—due to start around 2030—they can prevent nearly 60 gigatons of CO2 emissions (GtCO2)." The aftermath of the COVID-19 pandemic presents an opportunity to redouble the efforts to green the economy, and the remarkable speed with which vaccines were developed shows that the lags in commercializing and scaling up innovative technologies[89] can be dramatically shortened with the right incentives backed with adequate financing.

81 Bhattacharya et al (2021) provide an exhaustive review of policy options/initiatives. Climate action to unlock the inclusive growth story of the 21st century. https://www.imf.org/en/Publications/WP/Issues/2021/05/26/Climate-Action-to-Unlock-the-Inclusive-Growth-Story-of-the-21st-Century-50219

82 https://www.economist.com/graphic-detail/2021/08/07/how-climate-targets-compare-against-a-common-baseline

83 W. Nordhaus (2015) Climate clubs. https://www.aeaweb.org/articles?id=10.1257/aer.15000001; https://ec.europa.eu/commission/presscorner/detail/en/qanda_21_3661

84 R. Calleja (2021) How do development agencies support climate action. https://www.cgdev.org/sites/default/files/PP207-Calleja-Agency-Action-Climate.pdf; I. Mitchell et al (2021) https://www.cgdev.org/blog/whose-climate-finance-new-and-additional

85 https://www.iea.org/reports/clean-energy-innovation/global-status-of-clean-energy-innovation-in-2020

86 https://www.vox.com/energy-and-environment/21426920/climate-change-renewable-energy-solar-wind-innovation-green-new-deal

87 https://www.iea.org/reports/clean-energy-innovation/global-status-of-clean-energy-innovation-in-2020

88 IEA (2020) https://www.iea.org/reports/clean-energy-innovation

89 "History shows that bringing new energy technologies to sizeable deployment after the first prototype can take between 20 and almost 70 years: the journey took around 30 years even for recent highly successful clean energy technologies, such as solar photovoltaic (PV) and lithium-ion (Li-ion) batteries to power electric vehicles." IEA (2020) https://www.iea.org/reports/clean-energy-innovation/clean-energy-innovation-needs-faster-progress

We do not need to live with intensifying heat waves. We have the technology and the policy tools to first slow and then halt global warming within three decades—before critical tipping points are breached. We have the resources as the response to COVID-19 demonstrated. A cessation of futile negative-sum arms races could free even more resources. But neither the brutal pandemic nor the ringing calls to build back better and greener have persuaded enough of those who shape politics and policy to suspend doubts and to ensure that livability on this planet does not continue deteriorating slowly and then sharply. The IPCC's most recent report (2021) might just tip the balance in favor of those calling for a far-reaching response to the brewing crisis, which would dwarf the damage inflicted by the COVID pandemic. As Mike Berners-Lee (2019) observes, "There is no Planet B."[90] The little green men looking longingly at our blue planet from a desolate hilltop on Mars must be shaking their heads in disbelief.

90 Cambridge University Press.

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