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Accounting for Climate Risks in Costing the Sustainable Development Goals

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ABSTRACT: This paper evaluates the additional spending needed to meet core targets of selected Sustainable Development Goals (SDGs) while accounting for the associated cost to address climate risks. The SDGs under study are those related to human and physical capital development. An additional 3.8 percent of global GDP, or US$3.4 trillion, of public and private spending will be required by 2030 to achieve a strong performance in the selected SDGs while addressing associated climate risks. This includes an increase of 0.4 percent of global GDP (US$358 billion) compared to estimates that do not account for mitigation and adaptation needs within these sectors. LIDCs and SSA experience the highest climate-related cost augmentation relative to GDP, while EMEs (driven by large Asian emerging economies) bear the largest cost in absolute terms.

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WORKING PAPERS

Accounting for climate risks in costing the Sustainable Development Goals

Prepared by Rimjhim Aggarwal, Piergiorgio Carapella, Tewodaj Mogues[2], and Julieth Pico-Mejía[1]

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I. Introduction

Climate change is one of the defining challenges of our era, with direct and indirect implications for key areas of service and infrastructure provision that affect human welfare, including in health, education, water and sanitation, electricity, and road infrastructure. The world finds itself past the midpoint between the conception of the Sustainable Development Goals (SDGs) in 2015 and the year by which significant progress should be made toward these goals, 2030. It is at this time imperative to understand not only the resource needs associated with achieving a high performance in key targets of the SDGs concerned with human and infrastructural development, but also to assess the additional implications for spending to tackle, within these SDGs, key climate-mitigation goals and adaptation needs. It was recognized already decades ago—for example, in a landmark review of the economics of climate change—that the costs of *not* acting to address climate change are much higher than the costs of taking action (Stern, 2007). Hallegatte et al. (2019b) estimate that adapting infrastructures to climate change is highly cost effective, with a global net present value of over $2.5 trillion.[1]

This study extends previous IMF analysis (Gaspar et al., 2019) and its updated estimates (Carapella, Mogues, Pico-Mejía and Soto, 2023) that assess the additional spending needed to meet core targets in selected SDGs to support human and physical capital development—specifically SDG 3 (health), SDG 4 (education), and key targets in SDG 6 (water and sanitation), SDG 7 (electricity access), and SDG 9 (road infrastructure). This paper's extension consists of accounting for the additional cost to address climate risks within these five sectors. While other IMF work has carried out climate-related SDG cost assessments for single countries or for a small group of countries (e.g. Daniel et al. (2020) for Tonga, Mogues et al. (2023) for Namibia,[2] Nose (2021) for the Solomon Islands, and Tiedemann et al. (2020) for small developing states), this study develops a systematic approach and draws on data that enables the generation of country-level desk estimates globally (specifically, for 173 countries; see more detail on country coverage in Table A1 in the Appendix).

Each sector's methodology, which is tailored to the specificities of the respective SDG areas, is presented in detail in the sections to follow, and we offer a general overview here. The paper assesses both the additional adaptation and mitigation costs within the SDGs of focus. The former includes the cost of making infrastructure—such as water reservoirs and other facilities in SDG 6, roads in SDG 9, etc.—resilient by reducing the damage probabilities of the extreme weather events and other existing and future manifestations of climate change that affect the sector. In the sector in which adaption to climate risks is highly multifaceted, namely in health (SDG 3), we assess the additional expenditures a country faces to achieve the adaptation spending of countries with i) similar levels of exposure to climate-change-induced extreme weather events and

[1] The broad finding, although the estimates of the many scenarios considered vary in magnitude, is very robust: Out of around 3,000 different scenarios, 2,904 of them have a cost-benefit ratio smaller than one.

[2] This report is summarized in Annex IX of the IMF's 2023 Article IV staff report for Namibia, IMF (2023c).

ii) that are effective in reducing their vulnerability to this exposure. Our study accounts for adaptation in all five sectors. In so doing, the analysis accounts for the fact that climate change impacts in these sectors are not only ahead of us: A large number of extreme event attribution studies have found that many such events that have caused setbacks in basic infrastructure and service provision to make progress in the SDGs were strikingly more likely to have taken place as a result of the warming the world has experienced to date (IPCC, 2021).

Second, the study considers additional mitigation costs in the primary sector for which such costs are significant. Energy accounts for 34 percent of total greenhouse gas emissions (Lamb et al., 2021), thus our analysis accounts for mitigation in SDG 7. We estimate the additional expenditures to contribute to climate mitigation standards, by shifting to renewable energy for electricity production (related to SDG 7).
Existing standards in mitigating within the education sector, along with available estimates, also enable us to consider mitigation costs in SDG 4, relating to the additional cost of accommodating the 'green schools' standard in building new educational facilities.[3]

Other large emitting sectors are industry (24 percent of total greenhouse gas emissions), agriculture and related land use (21 percent), transport (14 percent), and buildings (6 percent). Of these, the transport sector may relate most closely to the SDGs of focus in this paper. While this sector contributes nontrivially to emissions, our analysis of SDG 9 does not focus on the broader sector but only on road infrastructure. In regard to the other remaining infrastructure sector from among the five SDGs of interest in this study, as stated in IWA (2022), "[w]ater and climate questions are usually addressed from the perspective of adaptation to climate change. For the water sector the mitigation aspect has been less studied up till now." Given this prioritization of adaptation in the literature and scarce attention to mitigation, our analysis similarly retains an adaptation focus in the context of SDG 6. Finally, on SDG3, estimates suggest that while health care systems are responsible for 4.4 percent of emissions, only 17 percent of these (i.e., 0.7 percent overall) are in Scope 1 (Setoguchi, Leddin, Metz and Omary, 2022).[4] This factor, combined with the absence of well-established and quantified mitigation standards in the health sector (unlike in education) means that we do not quantify additional emission reduction costs in SDG 3.

Our findings reveal that an additional 3.8 percent of global GDP, or US$3.4 trillion, of public and private spending will be required by 2030 to achieve a strong performance in the selected SDGs while addressing associated climate risks.[5] This includes a sizeable annualized increase of 0.4 percent of global GDP (US$358

[3] These mitigation measures can naturally also have co-benefits across sectors, for example, increased use of renewables to meet the electricity needs can reduce the adaptation expenditure requirements in the other SDGs. However, Laumann et al. (2022) seem to find only weak if any linkages between the five SDGs of focus in this study.

[4] The Greenhouse Gas Protocol established three scope categories: Direct emissions from a given sector (e.g., health care) are captured in scope 1, indirect emissions from the sector (e.g., from the health sector, through purchased electricity, cooling and heating for health facilities and equipment) are categorized into scope 2. Scope 3 emissions are those emanating from the production, transport, etc., of goods, services and infrastructure related to the sector—e.g., emissions from transportation of medical goods.

[5] The results section of the paper discusses our results with that in the literature.

billion) in 2030, compared to estimates that do not account for mitigation and adaptation needs within these sectors. The distribution of global additional expenditure shifts more towards the infrastructure sectors when climate risks are considered. Differences in cost burdens emerge across income groups and regions, with LIDCs and SSA experiencing the highest climate-related cost augmentation relative to their GDP—in addition to the fact that this income group and region faces by far the largest spending burden to attend to core SDG needs. EMEs (driven by large Asian emerging economies) bear the largest climate-related additional cost in absolute terms. The composition of both the core and the climate-related additional SDG expenditure needs differs importantly by income group, underscoring the necessity for tailored strategies and substantial international cooperation and financial support.

The estimates presented in this paper can be of relevance to stakeholders at the national and multi-national levels. For example, at the September 2023 SDG Summit, which marked the halfway point of the SDG period from 2015 to 2030, the United Nations High-level Dialog highlighted the challenge of finding innovative financing options to meet the SDG spending needs against the backdrop of escalating climate change.[6] Our estimates at the national level, when further refined through capacity development engagement with the respective countries, can help inform National Adaptation Plans (NAPs) and Nationally Determined Contributions (NDCs). Moreover, as countries strive to align their budgets with SDG targets, understanding the climate-adjusted cost of these goals is vital.

It is crucial to distinguish between the scope of this paper and the broader context of climate-related Sustainable Development Goals that explicitly address climate action, e.g., SDG 13 focuses on urgent actions to combat climate change and its impacts. This paper focuses on mitigation and resilience related actions *within* SDGs 3, 4, and selected targets within SDGs 6, 7 and 9, and does not attempt to quantify spending required to achieve climate goals in other SDGs, including those with an explicit focus on climate action such as SDGs 13 and 14. The evaluation of costs associated with direct climate action such as decarbonizing economies, strengthening resilience across a wider array of sectors (beyond the five sectors of focus in this paper), and improving overall adaptive capacities to climate-related hazards, falls outside the purview of this paper and are analytical challenges in their own right, handled elsewhere in the literature.

Recognizing the complexities of climate science, we acknowledge that there are inherent limitations and uncertainties associated with the cost estimates we have derived. There are also uncertainties regarding the availability and costs of future technologies that could be used for mitigation and adaptation efforts, and regarding relevant demographic and socio-economic variables. The methodology section associated with each SDG outlines the limitations in scientific understanding, data quality and availability, model construction and assumptions, and the application of experts' judgment where needed.

[6] https://www.un.org/sustainabledevelopment/blog/2023/09/press-release-with-trillions-needed-to-achieve-sustainable-development-goals-world-leaders-gather-to-set-out-bold-solutions-to-urgently-scale-up-investments/

The remainder of the paper is structured as follows: Sections II through VI present brief overviews of the relevant mitigation and/or resilience needs related to specific core targets in the respective SDGs on health, education, water and sanitation, electricity, and road infrastructure. Each of these five sections then proceed to provide a detailed discussion of the methodology and data used to carry out the assessment of the additional spending to adequately address the climate risks in each of the sectors. Section VII gives the results of our analysis, presenting the findings globally, by income group, and by region. In so doing, it contextualizes the magnitude of the climate-related costs by comparing them to the previous analysis of spending needs that do not account for climate risks. Table A2 in the Appendix reproduces the main results in tabular form. Section VIII concludes by summarizing the key findings and identifying potential directions for future research.

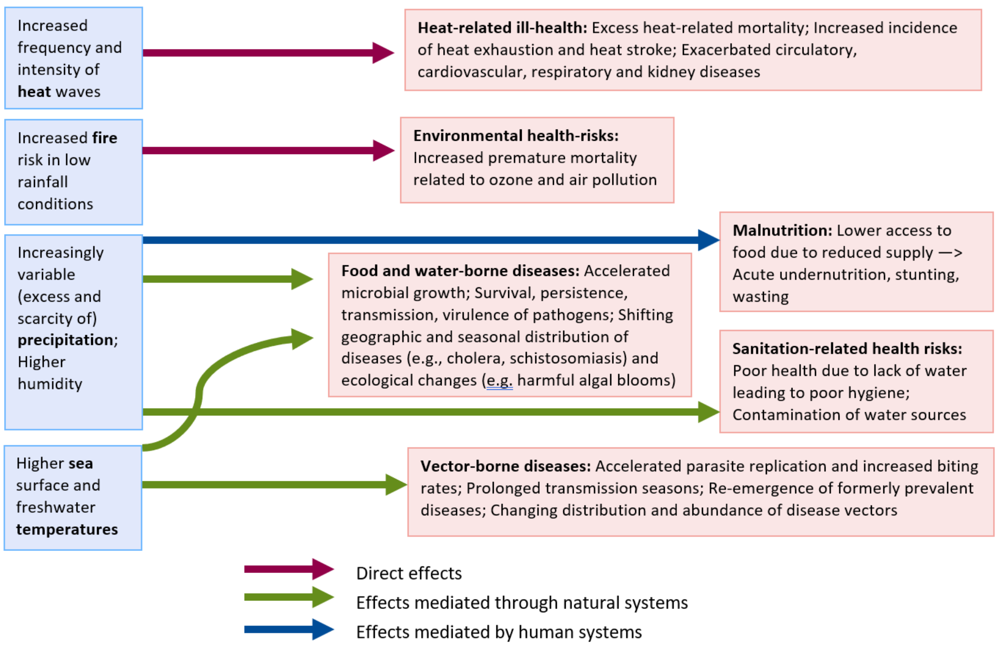
II. Health (SDG 3)

A. Background

Climate change has significant implications for human health (Romanello et al., 2023), and addressing these is paramount, particularly in the context of SDG 3, which calls for ensuring healthy lives and promoting well-being for all at all ages. Without adequate adaptation measures, climate change will exacerbate existing health risks and introduce new challenges, undermining the progress towards SDG 3 by and beyond 2030. This section examines the necessary adaptation measures for health systems to respond effectively to climate change and estimates the costs of implementing these measures.

A changing climate has direct and indirect health consequences (Figure 1). Impacts may be direct, through the mortality and morbidity effects of extreme heat and weather events such as a storms, forest fires, floods, or droughts, or indirectly mediated through the ways that climate change bears on ecosystems (disease patterns, agriculture), economic activity (e.g., air pollution) and social structure (e.g., migration and conflict leading to violence, which causes physical harm) (Watts et al., 2015; Filho et al., 2016). Vulnerable populations, such as the elderly, children, and those with pre-existing health conditions, are disproportionately affected by these consequences (Benevolenza and DeRigne, 2019).

Figure 1. Direct and Indirect Effects of Climate Change on Health



Source: Authors, based WHO (2015) and IPCC (2014).

Adjusting health systems to climate change requires a comprehensive approach, encompassing prevention, preparedness, response, and recovery measures. Prevention measures, including the reduction of greenhouse gas emissions, lie primarily outside of the health sector itself, while preparedness involves enhancing public health infrastructure, surveillance, and early warning systems (Wu et al., 2016). Effective response strategies involve timely and appropriate interventions, such as the provision of emergency medical care during extreme weather events (Aitsi-Selmi et al., 2015). Finally, recovery measures focus on rebuilding health systems after realized climate-related health damage (Kruk et al., 2015).

Given the urgency of achieving SDG 3 by 2030, understanding the fiscal implications of adapting health systems to climate change is crucial for policy planning and resource allocation. We provide a country-level estimation of the additional expenditure needed to achieve SDG 3 in a manner that accounts for the necessity to adapt health systems to climate change.

B. Methodology

The empirical approach develops a benchmarking approach analogous to that in Gaspar et al. (2019) to estimate the expenditure for putting in place measures to adapt health systems to the impacts of climate change on the health sector. This entails identifying countries' health systems' current as well as future exposure to climate change (Section 1), their performance in reducing vulnerability in the face of this exposure

(Section 2) and assessing the additional cost to achieve a good performance in adapting health systems to climate risks based on future exposure levels, by benchmarking countries to the high performers among peers with similar levels of exposure (Section 3).

1. Current Health Exposure to Risks Exacerbated by Climate Change

Exposure to climate risk refers to the extent to which a country directly or indirectly comes into contact with the physical effects of a changing climate, such rising sea levels, more frequent and intense heat waves, more severe weather events, and changes in precipitation patterns. Exposure can vary depending on a range of factors such as geography and demographics. The IPCC Third Assessment Report (IPCC, 2001) distinguishes between exposure and vulnerability, as “the nature and degree to which a system is *exposed to* significant climatic variations” and “the degree to which a system is susceptible to, or unable to *cope with*, adverse effects of climate change, including climate variability and extremes.” While the level of exposure is largely independent of the menu of direct measures countries’ decisionmakers can take, the level of readiness or vulnerability depends on various factors such as countries’ resources, policies, infrastructure, and governance. Measuring exposure to climate change helps in identifying the specific threats a country is facing and in ultimately determining the additional expenditure needs to adapt to this risk effectively.

To measure the exposure of the health system to climate change, we consider three principal dimensions defined by IPCC (2014) and WHO (2015): (i) health impacts of climate-change-exacerbated extreme weather and disaster events, (ii) exposure to climate-sensitive parasitic and viral diseases, and (iii) exposure to the risk of malnutrition brought about by climate change. We aim to approximate the level of exposure using exogenous variables that capture the effects of climate change, as the goal in this first step is to build an exposure (as opposed to a vulnerability) measure that does not take into account response capacity.

a. Health exposure to climate-change-induced extreme weather and disaster events
)

We develop metrics and draw on variables that reflect the exposure of people’s health to key types of extreme weather and disaster types that are becoming more frequent and intense with climate change:

Heatwaves: This indicator tracks the change in the number of heatwave exposure events (with one exposure event being one heatwave experienced by one person aged over 65 or under 1 year old). The change from the latest year (2020) in this variable is measured with respect to the cross-year average in the reference period (1986–2005). A heatwave is defined as a period of at least two days during which both the daily minimum and maximum temperatures are above the 95th percentile of their respective climatologies.

Wildfire: This variable uses both model-based wildfire danger and satellite-observed exposure. Climatological wildfire danger is estimated by combining daily ‘very high’ or ‘extremely high’ wildfire danger (a fire danger index score of 5 or 6, respectively, on a range of 1-6) with climate and population data. Human exposure to wildfires in person-days (with one person-day being one person exposed to a wildfire in one day) is tracked using satellite and population data. The indicator uses values from a recent (2017-2020) four-year average.

Droughts: Exposure to drought is measured by a combination of two factors: the risk of drought, and the population affected by droughts in recent years (materialized risk). For the first factor, the model defines an agricultural drought as a dry period in a location in which at least 30 percent of the crop area was in stress for more than 10 days. This is measured using the Agriculture Stress Index (ASI), which is based on the integration of the Vegetation Health Index (VHI) in temporal and spatial dimensions. First, the VHI is averaged over time at the pixel level, assessing the intensity and duration of dry periods occurring during the crop cycle. Then, the percentage of pixels in arable areas with a VHI value below 35 percent (lower values indicate greater vegetation stress) is derived. A country is considered in drought in a particular year if the ASI indicates drought in one or more crop seasons. The drought probability is based on the country's frequency of droughts within the last 30 years. The second factor considers the number of historically affected people per year (both absolute, and relative to the country's population size) based on historical events for the last 25 years. To emphasize drought-prone countries with frequent and extensive drought, as well as to compensate for uncertainty associated with unique, intensive drought events, we take the mean between the average annual size of the drought-affected population and the frequency of drought events.

Floods, tsunamis, and tropical cyclones: Hazard zones for each event type are obtained from hazard maps and the event types' return-periods. The hazard zones encompass the areas prone to occurrence of an event of at least the minimum intensity level that can trigger significant damage causing a disaster. Hazard zones are then overlaid with a population distribution model in order to derive the total population living in the hazard zone. This is then the population exposed to the specific hazard type and return-period.

There are two ways to consider population exposure to natural hazards by country. A metric relying on the (unnormalized) number of exposed people will raise the exposure index of more populated countries (*ceteris paribus*), while the share of the total population that is exposed will reverse the problem and elevate exposure values of less populated but hazard-prone countries, including small islands where most of the population may be affected by a single cyclone. Following the methodology developed by the Notre Dame Global Adaptation Initiative (Chen et al., 2015), the mean of both the absolute and relative population exposure is used (after applying a log transformation of the absolute number of exposed people, since the distribution of this variable is heavily skewed), and each indicator x is finally rescaled to range from 0 to 10 through a min-max normalization for each country i:

$$\tilde{x}_i = 10 - \left(10 \frac{x^{max} - x_i}{x^{max} - x^{min}}\right)$$

b. Exposure to climate-sensitive parasitic and viral diseases

The suitability of a physical environment for transmission of many infectious diseases is influenced by shifts in temperature and precipitation. In our analysis, this dimension is composed of the following variables:

R0 of Aedes aegypti and Aedes albopictus: This indicator measures the environmental suitability for the transmission of arboviruses (dengue, chikungunya, and Zika). It is based on a model that captures the influence of temperature and rainfall on vectorial capacity and vector abundance, overlaid with human population density data, to estimate the R0 (the expected number of secondary infections resulting from one infected person). The average of the indicators for these two vectors serves as the variable in the analysis.

Malaria transmission season length: The influence of the changing climate on the length of the transmission season for Plasmodium falciparum malaria is measured by a threshold-based model that incorporates precipitation accumulation, average temperature, and relative humidity.

c. Exposure to risk of malnutrition attributable to climate change

Climate change is projected to undermine food security (IFPRI, 2022). For wheat, rice, and maize in tropical and temperate regions, climate change without adaptation is projected to negatively impact crop production for local temperature increases of 2 degrees celsius. Global temperature increase, combined with increasing food demand, would pose large risks to food security globally. The set of indicators we use measures the change in crop growth duration—the time taken to reach a target sum of accumulated temperatures, which is a proxy for crop yield potential—for maize, winter wheat, spring wheat, rice, and soybean. The change is measured against a 1981-2010 reference period. In particular, crop growth duration is measured by the 11-year rolling average of the number of days to reach a target sum of accumulated thermal time (ATT) for each of the five staple crops. A negative value for the change in ATT relative to the reference period means that the crop growth duration is shortened, resulting in a more rapidly maturing crop that translates into smaller crops and lower yield.

A composite weighted-average indicator is created, with weights *w* for crop *c* reflecting the importance of each of the *n*=5 crops in a given country, and based on the value of production *Y*:

$$w_c = \frac{Y_c}{\sum_{c=1}^{n} Y_c}$$

The indicator is then removed of outliers, with outliers *x* for country *i* fulfilling either of the two conditions:

$$x_i < Q1 - 1.5 \cdot IQR$$

$$x_i > Q3 + 1.5 \cdot IQR$$

where $Q1$ and $Q3$ are the first and third quartiles, respectively, and *IQR* is the interquartile range. Min-max normalization is applied to the non-outlier observations.

d. Construction of an overall climate-change exposure measure by country, and of exposure groups

The indices on exposure to tsunamis, floods, tropical cyclones, drought, and wildfire are composed using data from the European Commission's INFORM Risk database. Exposure to heatwaves and indicators of climate suitability for vector-borne transmissions and exposure to malnutrition arising from climate-induced food availability changes are based on data from the Lancet *Countdown*.

We construct an exposure measure across all m=8 exposure types (health exposure to heatwaves, wildfires, cyclones, tsunamis, floods, droughts, malaria, arboviral diseases, food scarcity) using a weighted average of the indicators for each type. The weights w represent the gravity of each exposure type e by country, measured as the proportion of deaths D attributable to that particular exposure type:

$$w_e = \frac{D_e}{\sum_{e=1}^{m} D_e}$$

In this final exposure measure computed for each country, a higher value reflects a higher degree of exposure. Based on this variable, five country groups are formed, with an equal number of countries in each. These groups' exposure levels can be characterized as very low, low, medium, high, and very high.

e. Future projected health exposure to climate change

To project future exposure levels across the three dimensions, we substitute certain variables in our existing exposure measure with their counterparts aimed at predicting future scenarios. Specifically, we replace four of the eight variables with indicators obtained from ND-GAIN's database. These indicators track changes within different dimensions under Representative Concentration Pathway (RCP) 4.5, representing a "moderate emissions scenario".[7]

Health exposure to climate-induced extremes: A *heatwaves* measure tracks the absolute change in the Warm Spell Duration Index (WSDI) from the baseline year (1960-1990) to the future projection (2040-2070). WSDI counts the number of days in which the daily maximum near-surface temperature exceeds the 90th percentile threshold for six or more consecutive days. A *floods* measure assesses the percentage change in flood hazard

[7] Representative Concentration Pathways (RCPs) are scenarios of emissions and concentrations of greenhouse gases. The commonly referred to four RCPs—RCP2.6, RCP4.5, RCP6.0 and RCP8.5—span the range from approximately below 2°C warming to high (>4°C) warming by the end of the 2100.

from the baseline year (1960-1990) to a future projection (2040-2070) based on predicted monthly maximum precipitation in five consecutive days. We rely on the current exposure measures for the remaining four weather hazards (tsunamis, tropical cyclones, droughts, and wildfire) as proxies for future exposure, given lack of available data on projections for these variables (see Section 1a).

Exposure to climate-sensitive diseases: We use the projected change in the vector-borne diseases indicator. This indicator captures the absolute change in malaria Length Transmission Season (LTS) from a baseline estimate (1980-2010) to a 2050 projection.

Exposure to risk of climate-induced malnutrition: This indicator, which forecasts changes in the food supply for rice, wheat, and maize, is built using the results from five crop models. The projected change is computed as the percentage change from a baseline (1980-2009) to a future projection (2040 to 2069).

Construction of an overall climate change exposure metric by country, and of exposure groups: Following the same methodology explained in Section 1d, we normalize each indicator's values on a scale from 0 to 10 for each country. Then, we construct a projected exposure measure by calculating a weighted average of the above indicators. In the final projected exposure measure, computed for each country, higher values reflect higher projected exposure levels. Based on this measure, we classify countries into five groups, with an equal number of countries in each group.

2. Performance in Reducing the Vulnerability of Health Systems to Climate Risks

Having developed the exposure measure, we next construct a measure of countries’ performance in reducing their vulnerability to climate risks on health: For each of the major avenues through which climate risks for health manifest, as detailed in the previous subsection, we identify parallel indicators that reflect the extent of countries’ use of resources to reduce their populations’ vulnerability to the given avenues of climate threats to the health sector. Following the earlier discussed method on normalization and on considering both relative and absolute dimensions of affected populations, the following four indices measure the performance in vulnerability reduction:

Heat related mortality: This indicator captures heat-related mortality in populations older than 65 years. It applies the exposure-response function and optimum temperature described by Honda et al. (2014) to the daily maximum temperature exposure of the population older than 65 years to estimate the attributable fraction and thus the deaths attributable to heat exposure.

Lethality of natural hazards (wildfires, floods, landslides, droughts, and storms): The variable sums the total deaths per country arising from each of these disasters. An event is considered a disaster if at least one of the following criteria are met: (i) 10 or more people die from the event, (ii) 100 or more people are affected by the event, (iii) the event triggers a declaration of a state of emergency, or (iv) the event triggers a call for international assistance.

Climate-sensitive parasitic or viral diseases: the indicator is the sum of deaths due to dengue and lymphatic filariasis, and total malaria cases.

Malnutrition attributable to climate change: The measure used is child stunting, specifically, the number of under-five-year-olds falling below -2 standard deviations (below -2 and -3 are defined as moderate and severe stunting, respectively) from the median height-for-age of the reference population. Severe irreversible physical and cognitive damage often accompanies stunted growth, with the effects at times lasting a lifetime and even affecting the next generation (Haile et al., 2021).

Then, analogous to the construction of the overall exposure measure, we create a weighted-average composite performance variable using as weights *w* the share of deaths from each of *n* event types *p* (extreme heat, natural hazards, parasitic or viral diseases, and malnutrition):

$$w_p = \frac{D_p}{\sum_{p=1}^{n} D_p}$$

A country is considered a high performer in reducing vulnerability if the normalized score is greater than 9. If more than ten countries in an exposure group meet this condition, only the ten highest performers in that group are considered.

3. Additional Expenditure to Adapt Health Systems to Climate Risks for the Achievement of SDG 3

The Lancet *Countdown* tracks spending on health adaptation to climate change by country (Romanello et al., 2022). This includes both public and private spending on measures aimed at reducing the health impacts of climate change, such as health infrastructure development, disease surveillance, disease control systems, and health workforce training, and includes key adaptation measures identified by the IPCC. The methodology used for data acquisition and analysis is based on a system called ‘profiling’, which was originally developed at Harvard Business School to track and analyze technical and industrial change. When measuring an industry or sector, the new taxonomy is populated from the bottom up, searching for evidence for the ideal definition and including only economic activities where sufficient evidence is available (see Romanello et al., 2022 for further methodological details).

The final step in the analysis brings together the current and projected future exposure, vulnerability, and health adaptation spending variables and applies the aforementioned benchmarking approach to arrive at an estimate of the additional climate adaptation spending needs for each country. Specifically, we consider a given country *i*’s peer group to be the projected exposure group to which it belongs, i.e., those countries whose health systems have a similar level of future exposure as country *i*. The country is then benchmarked against the set of 'good performers', i.e., those that are most effective in reducing their population's health systems to climate risks based on the current level of exposure and vulnerability measures. Thus, *i*'s additional expenditure to adapt health systems to climate change is the difference between the mean of the well-performing peers' and the country's per-capita health adaptation costs. We report the results with these costs expressed as a percent of 2030 GDP.

III. Education (SDG 4)

A. Background

Climate change poses serious risks to children's education and has the potential to undo significant gains made in advancing the 4th SDG. The United Nations Children's Fund (UNICEF) has thus called for "urgent actions to 'climate-proof' the education sector and to accelerate climate-resilient and climate-smart education investments and actions" (UNICEF, 2019). Climate change can impact the education sector directly through: effects related to the damage of education infrastructure, loss of education material, injury/mortality of students and teachers, and the impacts on learning of psychosocial stress resulting from exposure to extreme weather events. There are also less well understood indirect impacts on educational outcomes associated with climate effects on food security, livelihoods, air pollution, access to water, health, and energy (UNICEF, 2019, 2022). In turn, the education sector can also make significant contributions in building the capacity to deal with climate change. Article 6 on education, training, and public awareness of the UN Framework Convention on Climate Change (UNFCCC) calls for countries to develop and implement educational and public awareness programs on climate change and its effects.[8] The Paris Climate Agreement's Article 12 also reiterates the importance of the role of education in enhancing climate action (UN, 2015).

Globally there are 6.6 million schools that accommodate 1.6 billion students**,** 83 million teachers, and 41 million administrative staff, and the asset value of school infrastructure and contents is estimated to be US$13.6 trillion (World Bank, 2023). At the regional level, East Asia & Pacific holds the highest total school-asset value, while Sub-Saharan Africa has the lowest school-asset value. Educational infrastructure experiences large damages from climate change induced extreme events. For example, the Latin America & Caribbean and East Asia & Pacific regions have experienced the most damage from major tropical cyclone events in the past 50 years. Historical records suggest that the damage in the education sector could surpass 40 percent of the total direct damage of such cyclones (World Bank, 2023). The cumulative impact of tropical cyclones inflicts considerable destruction on schools and dramatically disrupts the educational system. An initiative, Global Program on Safer Schools (GPSS), collected and analyzed detailed school damage data for 20 tropical cyclone events in the period 1998–2018 with the aim of understanding relative vulnerability across events with different hazard

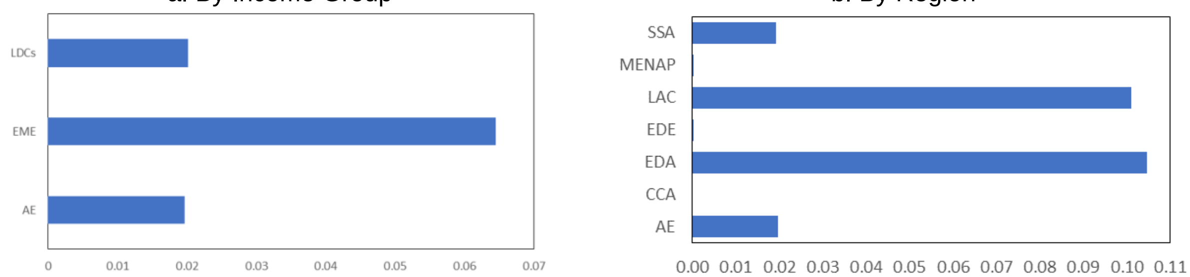
[8] https://unfccc.int/topics/education-and-outreach/workstreams/education-and-training

intensity and across the world (World Bank, 2020). For the wind impacts associated with these tropical cyclones, the average annual loss expressed as percentage of total exposed value of school capital stock is highest for Emerging and Developing Asia region (Figure 2). By income group, emerging and market economies (EMEs) have by far the highest loss as a share of exposed assets.

Figure 2. Annual Average Loss of School Building Stock from Tropical Cyclone Winds

(Percent of total exposed school asset value)

a. By Income Group b. By Region



Source: Authors' calculations based on World Bank (2023).

Despite this emerging evidence on losses in the education sector due to climate hazards, there is generally a lack of integration of education in climate priority settings. Out of the 196 Parties to the UNFCCC, less than one-third mention education in their Nationally Determined Contributions (NDCs) (UNICEF, 2019). Even this restricted inclusion of educational concerns in the climate change policies of countries is often limited to school curriculum and public awareness issues, failing to address the various pathways through which climate risks may undermine educational performance.

B. Methodology

A global review of educational facilities by UNESCO found that buildings and equipment have historically represented, at 20 to 25 percent, the second single largest element of spending in the sector, after teachers' salaries (Beynon, 1997). In this section, we lay out the methodology for the additional cost of adaptation to and mitigation of climate change in the education sector through a prospective investment program to strengthen resilience of school building infrastructure against major natural disasters by 2030 and to transition towards green schools. In recent years there has been an upsurge of interest in assessing the cost of building resilient infrastructure (Hallegatte et al., 2019a, b, Miyamoto, 2019a, b). However, the focus of this work has been on capital-intensive sectors such as power, telecommunications, water and sanitation, and transportation. The education sector has not been explicitly considered in any of these studies.

To adjust education infrastructure to climate change by 2030, we consider the costs of: (i) structural retrofit measures and replacement or reconstruction options for the current stock of school buildings to improve building performance in the face of major disasters, and (ii) construction of new buildings following the *green schools* standard. The concept of 'green schools' was formulated at the World Summit on Sustainable

Development (WSSD) held in 2002 and refers to schools that build on the holistic framework of Education for Sustainable Development (ESD) to create clean, healthy, protective and green surroundings in school campuses while saving energy, environmental resources, and building resilience against natural disasters (UNESCO, 2011; Kats, 2005).

1. The Costs of Retrofitting Existing School Buildings to Climate-Resilience

We estimate the cost of retrofitting or reconstructing the current stock of school buildings in country *i* as

$$RC_i = u \cdot K_i$$

where u is the average unit (per-square-meter) cost of retrofit measures and replacement/reconstruction options, and K_i is the total school building area (in m^2) in country *i*. Based on the estimated cost per square meter of building area for various physical interventions such as roof fixing/replacement, flood barriers, reinforced mortar layers, etc., we calculate the weighted average unit cost, using as weights the frequency with which these interventions were deployed in the case study from which the estimates were derived.[9] The total school building area to be retrofitted or reconstructed is derived as:

$$K_i = N_i \cdot S_i \cdot E_i$$

where N_i is the country-specific norm for the required school building area per enrolled student, averaged across the different types of schools. N_i is estimated based on UNESCO reports and other sources (Nge et al. (1992) for Asian countries, Vickery (1985) for eight West European countries, Beynon (1997) for global norms, and DOE (2014) for the UK). Income-region averages of school building area requirements are applied to countries for which no suitable building area data are available. S_i is the total number of enrolled students in each country, obtained from the World Bank's EdStats database. E_i is a country level exposure index ranging in values from zero to one, with higher values denoting higher levels of exposure to flood hazard.[10] As such, this variable proxies the share of school building area in a country that is exposed to climate risk.

The additional annualized spending needed to make schools climate resilient by 2030 is, then, estimated as:

[9] u is calculated from cost estimates in the report on Safe Schools of the project Global Facility for Disaster Reduction and Recovery (GFDRR) (World Bank, 2022). Due to scarcity of granular data on the costs of various retrofits/replacements, we used data on Tonga as a proxy for global unit costs of retrofits and reconstruction/replacement measures. While Tonga is a country with high climate exposure, this fact does not bear on the *unit* cost. The weighted average unit cost of various retrofit interventions is estimated to be US$156.

[10] From the ND-GAIN database, we used the measure of precipitation extreme under climate change, a risk factor for flood hazard, in particular, the projected percentage change in the flood hazard from the baseline (1960-1990) to a future projection (2040-2070), based on the RCP 4.5 “moderate emissions scenario”. (ND-GAIN, 2023).

$$RAC_{iT} = \frac{RC_i \cdot r}{1-(1+r)^{-n}}$$

where *r* is the discount rate (assumed to be 5 percent, following World Bank, 2022), and *n* is the number of years to the SDG end-year (10 in this case, given that much of the data pertain to 2020).

2. The Cost of Upgrading New Buildings Following the *Green Schools* Standard

Conventional schools are typically designed just to satisfy local building codes, which are often incomplete and poorly enforced (Kats, 2006). Although this strategy is chosen with the intention to minimize initial capital costs, it delivers schools that do not use resources efficiently and thus have higher operational costs, while also failing to provide comfortable and productive work environments for students, faculty, and staff. The UN Secretary General’s Transforming Education Summit in 2022 emphasized that education must be transformed to respond to the global climate and environmental crisis. Beyond adapting school building infrastructure to climate change, there is a growing trend towards building “green schools” that can contribute to climate mitigation goals by creating structures and using processes that are environmentally responsible and resource-efficient throughout a building’s life cycle (UNESCO, 2011, EPA, 2017). Greening school design can also provide co-benefits, including reduced operational costs (for example, typically around 30 to 50 percent reduction of energy and water use), lower maintenance costs, and other benefits (Kats, 2006, Yudelson, 2008).

While there is growing consensus around the benefits of greening school buildings, there is not much consensus around the green cost premium, defined as the differential in the upfront cost between the green and conventional “version” of the same building (Kats, 2005). This lack of consensus stems from: the wide variation in what is considered “conventional” across different local contexts, the difference in rating systems used to assess green buildings, and the absence of a standard methodology for estimating this cost premium. A global review of 17 empirical studies, which used a rigorous methodology to estimate this premium, found it to vary between –0.4 to 21 percent (Dwaikat and Ali, 2016). The review highlighted only a few cases where the cost of green building is lower than that of a conventional building while in most cases the cost of greening was found to be much higher. Another widely cited study (Kats, 2010) that collected data on more than 170 green buildings in the US and other developed countries also found a wide variation in cost premium—ranging from 0 to 18 percent. However, more than three-quarters of the analyzed green buildings in the latter study fell within the range from 0 to 4 percent, with a median value of around 2 percent. While these studies considered green buildings in general, studies using a similar methodology but a smaller sample of green schools found that these tend to cost around 2 percent more on average than conventional schools in the U.S. (Kats, 2006).

The average green cost premium of 2 percent may seem low, given the slow uptake of green schools. Researchers have attributed the slow uptake to the general perception of much higher initial investment costs, and lack of awareness about potential major cost savings (Meron and Meier, 2014). Further, there is evidence that several schools commit their investment decisions based on the estimates of the initial construction cost, with little or no consideration for costs relating to operation and maintenance (O&M) throughout the life of the building (Weerasinghe and Ramachandra, 2018). As part of UNESCO's contribution to the Greening Education Partnership, efforts are currently underway to promote awareness about, and develop a quality standard on, green schools. For our purpose in this study, we draw on the review above to apply a uniform 2 percent cost premium to meet green schools standards for new investments in school buildings between 2020 and 2030 while acknowledging that actual green cost premiums may be quite sensitive to local conditions.[11] The additional costs to meet green schools standards for new investments in school buildings is estimated as

$$NC_{iT} = \alpha\, E_i K_{iST}$$

where K_{iST} is the new capital investment spending in schools at time T = 2030 for meeting SDG 4 in country i, and α = 0.02 is the green schools cost premium.

Finally, bringing together the costs of retrofitting exposed existing school infrastructure (RAC_{iT}) and upgrading new schools infrastructure NC_{iT} following the green schools standard, the additional total costs (TC_{iT}) in 2030 for meeting SDG 4 in country i with attention to climate resilience requirements for educational facilities is estimated as:

$$TC_{iT} = RAC_{iT} + NC_{iT}.$$

IV. Water and Sanitation (SDG 6)

A. Background

1. Overview

Water, and thus SDG 6 (clean water and sanitation) is at the frontlines of climate change. The water cycle is the main channel through which the impacts of climate change are experienced across the various sectors of the economy, society, and environment: via precipitation, storm surges, floods, droughts, hurricanes, rising seas, and groundwater recharges (Douville et al., 2022, World Bank, 2016). The Sixth Assessment Report of the IPCC confirms that significant changes to the world's water cycle are already underway, and that these changes will likely grow in the future (IPCC, 2021).

[11] The reviews of Kats (2005, 2006) are focused on educational facilities in the U.S. alone, while Kats (2010) covers green buildings in a few other developed countries as well. The general finding here is that the green cost premium is lower for schools relative to other (office) buildings. We could not find studies using a similar methodology for green cost premium estimation in lower income countries, e.g., in EMEs and LIDCs, but we expect the premium to be higher in these countries given the lower base of conventional building quality and higher cost of green technologies, thus our estimates may constitute a lower bound. A study in Sri Lanka, for instance, found the premium to be 20-25% for green buildings (Weersinghe and Ramachandra, 2018).

A few studies have estimated the costs of achieving universal coverage of water, sanitation, and hygiene (WASH) services (SDG targets 6.1 and 6.2) at the global and country levels (Hutton and Varughese, 2016; Gasper et al., 2019; SDSN, 2019; WRI 2020; Carapella, Mogues, Pico-Mejía and Soto, 2023). However, none of these studies accounted for how climate change is likely to affect these costs. Under business-as-usual, most climate change models predict that water scarcity will proliferate to regions where it currently does not exist, and is likely to worsen in regions where it already exists. These trends related to water scarcity bring attention to the availability of adequate water to achieve universal coverage of WASH services. The greater frequency and intensity of climate hazards also threatens the capacity of existing infrastructure to continue the delivery of WASH services.

Challenges in estimating the additional costs due to climate change derive in large part from uncertainty surrounding long-term climate projections. Global circulation models (GCMs) have not been designed to project changes in the hydrological cycle, with the latter treated as just one element of a larger climate system (Douville et al., 2022). This imprecision is further compounded when models are extended to finer spatial scales that are needed for policy and decision making. The predicted climate impacts on water availability can thus be highly uneven across regions (World Bank, 2016).[12]

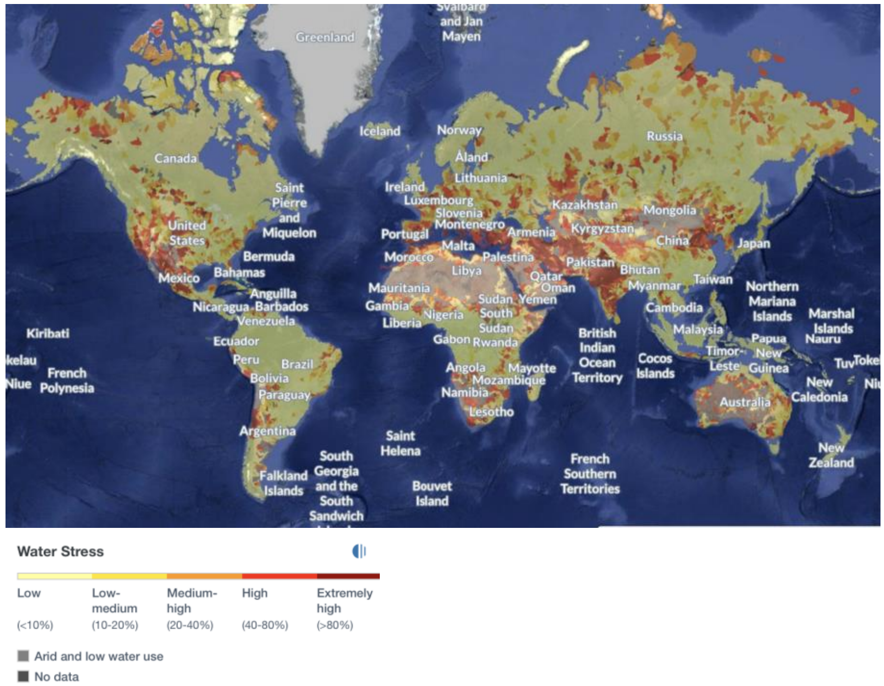
2. Distribution of Water Stress: Baseline versus Future Trends

Future trends in water availability due to climate change must be viewed in the broader development context where population growth, rising incomes, and rapid urbanization will continue to intensify competition among alternative uses of water—domestic, industrial, agricultural, and environmental. A commonly used indicator of this competition is water stress, defined as the ratio between total water withdrawals and available renewable surface water (Luck et al., 2015). While several recent studies have modeled long-term projections of climate change impacts on water availability, these projections are often for time periods too far in the future to be salient to decisionmakers. To provide information for decadal-scale planning, the World Resources Institute (WRI) modeled potential changes in future demand and supply at global scale for the period 2020 (taken as baseline) to 2050. This modeling was conducted for two climate scenarios: RCP 4.5, representing a “moderate emission scenario”, and RCP 8.5, representing a “very high emission scenario”.

Figure 3 shows the baseline (2020) distribution of water stress, with redder-shaded regions reflecting higher water stress. “High” and “extremely high” water stress areas include Mongolia, northern China, parts of south Asia and west Asia, as well as the Middle East and Mediterranean region, northern Africa, Sahel, southern Africa, Chile, south-western region of North America and south-western Australia.

[12] For example, increasing flood hazards are predicted for parts of South Asia, Southeast Asia, East Africa, Central and West Africa, Northeast Eurasia, and South America, and lower flood frequency in parts of Northern and Eastern Europe, Anatolia, Central Asia, Central North America, and Southern South America.

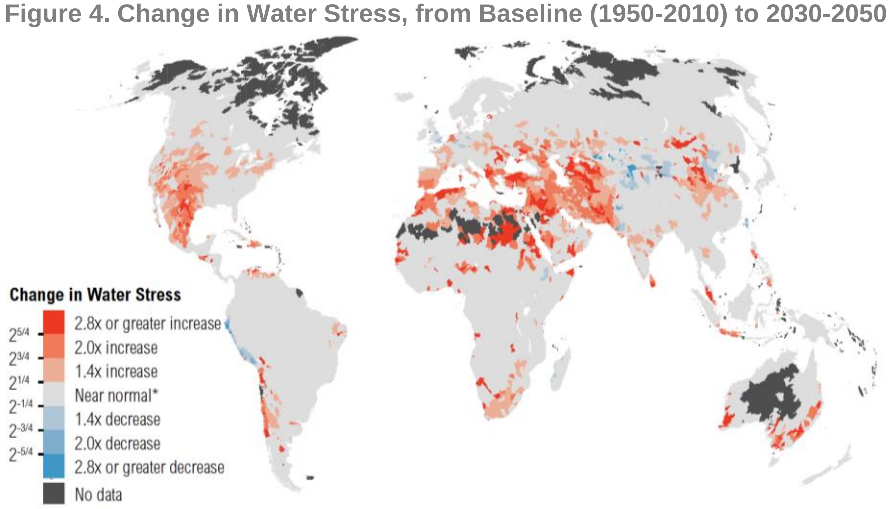
Figure 3. Baseline (2020) Water Stress



Source: WRI's Aqueduct Data Portal.

Projected change in water stress from baseline (2020) to future periods (2030–2050) is shown in Figure 4 under the "very high emission" scenario (RCP8.5 / SSP2): There is a large increase in water stress in many of the regions where water stress was already quite high in the baseline period. This includes much of the Mediterranean, Middle East and North Africa, parts of South Africa, the Murray-Darling River basin in Australia, and the southwestern region of North America.

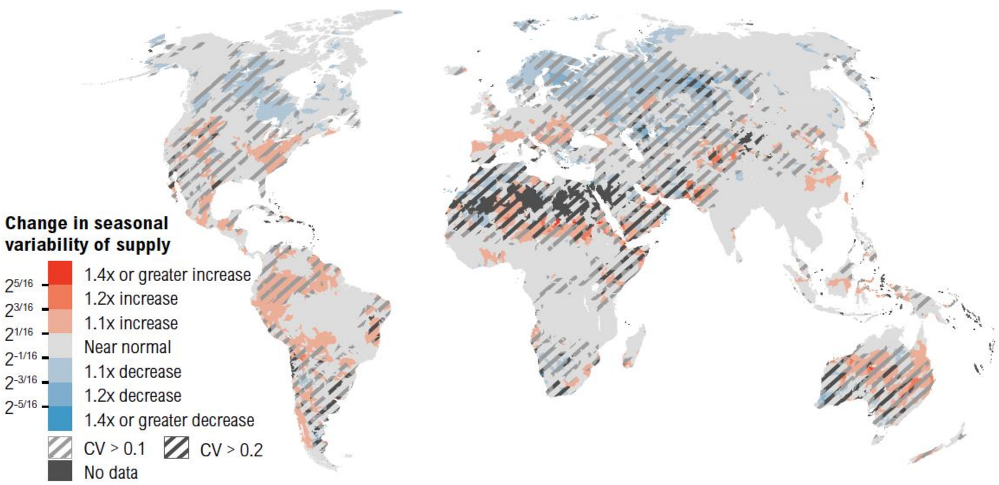
Figure 4. Change in Water Stress, from Baseline (1950-2010) to 2030-2050



Source: Luck et al. (2015).

Besides looking at these indicators over longer periods of time, it is also critical to pay close attention to seasonal variability (SV) of water supplies as these might challenge the SDG of universal water access at all times. Increasing SV may indicate wetter wet-months and drier dry-months, and higher likelihood of seasonal droughts that may pose serious challenges in locations without adequate reservoir capacity. Figure 5 shows projected changes in SV, measured as the within-year coefficient of variance between monthly total renewable surface water supplies. Even areas that are not expected to get drier may be exposed to increased SV. This is especially true in Sub-Saharan Africa, South Asia, Central Asia, and the southwestern parts of Latin America. Higher SV, compounded with the uncertainty in future changes, means that decision makers must plan for a wide range of possible outcomes.

Figure 5. Projected Change in Seasonal Variability of Water Supply



Source: Luck et al. (2015).

To address the varied challenges of water availability under climate change in an integrated manner, a wide range of strategies have been proposed (Bates et al., 2008; Kundzewicz et al., 2007). Among the supply side options, investments in storage infrastructure (such as reservoirs and dams) have been most widely adopted because these help smooth variability in water flows while also providing additional benefits such as hydropower generation and flood protection. But such technological options have come under increasing scrutiny because of their long term ecological and social impacts. Other supply-side options—such as desalination or groundwater pumping—are also expanding, but these may be inconsistent with climate change mitigation measures because of their high energy usage. From a sustainability perspective, nature-based solutions, such as wetland preservation, rainwater harvesting, and groundwater recharge are becoming more popular, but their structure and functioning is highly sensitive to the local bio-physical context. Interventions to manage the demand side through behavioral and policy changes have also been proposed and need to be integrated with supply side interventions to have lasting impact (Molle and Berkoff, 2007).

Given the underlying uneven impacts across time and space, the primary challenge for decision makers is to plan for a more uncertain and hazardous future, where general trends are known with greater confidence than the precise nature and timing of the changes (Ward et al., 2010). This calls for adaptable and flexible approaches that can respond to new information and changing circumstances. This is consistent with the perspectives of the IPCC, which has highlighted water as a key concern and focused on impacts and adaptation as part of the Working Group 2 (WG2) assessments (Douville et al., 2022).

B. Methodology

In this section we outline the methodology for estimating the costs for two complementary adaptation options to address the above discussed climate related risks to the attainment of the WASH targets of the SDGs. First, we build on previous analysis (Margulis and Narain, 2010; Ward et al., 2010) to estimate the costs of adapting to the increasing incidence of water stress globally through the construction of new infrastructure such as water storage and water reuse systems. Second, we estimate the costs of making WASH infrastructure itself more resilient to climate hazards. Studies on already realized climate hazards (e.g., hurricanes, cyclones, floods and droughts) found that most infrastructure, including that which was designed to endure under past climate conditions, cannot withstand the impacts of projected climate hazards. Miyamoto (2019a) provides a review of these studies and identifies the cost of specific structural improvements—both hard infrastructure adjustments, as well as the quality control—to reduce the vulnerability of various types of infrastructure. We build on this to develop estimates of additional water infrastructure resilience costs.[13]

1. The Cost of Adaptation to Water Stress through Construction of Additional Facilities

a. Features of a model of adaptation to water stress caused by climate change

We build on a study on the Economics of Adaptation to Climate Change (EACC) (Margulis et al., 2010) that focuses on low income and emerging market economies and covers eight major sectors, of which one is water supply. For each of these sectors, the analysis first establishes a future socio-economic baseline based on a set of consistent population and GDP projections. This baseline reflects a development trajectory set to meet sector-specific development goals but without attention to the effects of climate change. It then estimates the costs accounting for the impacts of climate risks. The additional costs of adapting to climate change are then the difference between the two sets of estimated costs. In this way, the study addresses a major limitation of previous work that confounded the costs of closing the development deficit and implicit adaptation deficit. Our estimation of the costs of adaptation draw on parameters from the EACC study,[14] with the understanding that in order to address water stress caused by climate change, adaptation calls for providing enough raw water to

[13] Beyond these adaptation options, several other measures also plays a critical role in climate adaptation. The latter may comprise the regulations, policies, insurance instruments, and a large variety of means to improve water use efficiency and related behavioral change on the demand side. We acknowledge the importance of these measures, but for the purposes of this global-scale study we focus our attention only on the infrastructure adaptation measures.

[14] See further details in Ward et al. (2010).

meet future industrial and municipal[15] water demand, based on demand and climate change projections until 2030 and 2050.[16] Box 1 summarizes the main steps in the EACC study.

Box 1. Modelling steps in estimating the additional water needs to adapt to climate change.

Water demand and supply projections: The effects of climate change on the water cycle are assessed by applying the Climate and Runoff Model (CLIRUN-II) on a monthly time-step. The results are aggregated at the level of the 281 food production units (FPUs) of the International Model for Policy Analysis of Agricultural Commodities and Trade (IMPACT) developed by the International Food Policy Research Institute (IFPRI). The 281 FPUs are then aggregated to the regional level (using the World Bank regional classification).

Climate scenarios: The climate scenario data used in Ward et al. (2010) are taken from two Global Circulation Models (GCMs): the Commonwealth Scientific and Industrial Research Organization's MK3 model (CSIRO_MK3) and the National Centre for Atmospheric Research's Community Climate System Model 3 (NCAR_CCSM3). These two models were chosen to capture a large range of model predictions—from extreme wet (NCAR) to extreme dry (CSIRO) scenarios—from among the 26 global climate models that provide climate projections based on the IPCC A2 emissions scenario from the Special Report on Emissions Scenarios (SRES) for the Fourth Assessment Report (AR4) of IPCC, carried out in 2007.

Sustainable expansion of supply: Increased water demand between present conditions and each of the two future scenarios is assumed to be met primarily through reservoir yield by increasing the capacity of surface reservoir storage, except:

- when increasing supply from reservoir yield would increase withdrawals to more than 80 percent of river runoff. There is an extensive literature devoted to determining how much water a river needs to sustain a healthy aquatic ecosystem function (for a review, see Tharme (2003)). The 80 percent threshold is taken as a general rule of thumb, in the absence of local bio-physical data.
- when the unit cost of supplying water from reservoir yield would be higher than US$0.30/m^3. In these cases, supply was assumed to be met through a combination of alternative backstop measures—such as recycling, rainwater harvesting, or desalination, at an average cost of US$0.30/m^3.[17]

[15] "Municipal" is not to be understood as focused on urban areas, but rather as household water use. Specifically, Wade et al. (2010) draws on data from FAO's AQUASTAT which defines municipal water "as the water we use for domestic, household purposes or public services. […] This is typically the most 'visible' form of water: the water we use for drinking, cleaning, washing, and cooking" (see https://ourworldindata.org/water-use-stress).

[16] Water used for irrigation purposes was considered in the EACC study as part of the agricultural sector analysis, and as such is not included in analysis of the water sector.

[17] Ward et al. (2010)'s estimates of reservoir storage capacity expansion draw on a data base of 85 costed reservoirs with a good geographical coverage over most of the World Bank regions (except for MENA region with relatively few reservoirs). The global average cost of this adaptation option was estimated to be US$0.13/m^3 in (in 2005 USD), but as expected, they found a lot of variation in these costs across regions. The cost of alternative adaptation options reported in their study also varies widely: ranging from around US$0.03/m^3 to US$0.25/m^3 for rainwater harvesting at the lower end, to desalination costs at the upper end

(continued…)

Aggregation to the regional level: Since the impacts of climate change are unevenly distributed, some regions are expected to lose and thus have positive costs of adaptation, while other regions are expected to gain and thus have negative costs (i.e., benefits, or avoided costs). In the process of aggregation, two approaches were followed. In the first approach, referred to as the net approach, the costs (positive and negative) were calculated for each country, and then averaged for each five-year period, before being aggregated to regions. In the second approach, referred to as the gross approach, the negative costs were set to zero before aggregation.

Source: Margulis et al. (2010).

b. Application of the model to estimate costs of adaptation to water stress

For our study, we use the gross cost estimates for the NCAR and CSIRO climate scenarios, to get the range of possibilities associated with climate change. The EACC study estimated the cost of adaptation as the cost of providing enough raw water to meet future industrial and municipal water demand. Thus, we need to extract the household (i.e., municipal) component alone, which corresponds to WASH services. Using data from the World Bank's World Development Indicators and WHO/UNICEF Joint Monitoring Program (JMP) for Water Supply and Sanitation, we derive the share of municipal water use in the combined municipal-and-industrial water use for each country, and apply this share to the cost estimate.

2. Existing WASH Infrastructure Improvement Costs to Enhance Resilience

Much of the critical WASH infrastructure systems worldwide are in areas that are subject to risks from various climate hazards. Engineering solutions have been developed and implemented to help mitigate this risk and the associated vulnerabilities related to WASH services. A high-level project assessed the these engineering solutions and the associated costs (Hallegatte et al., 2019a, b; Miyamoto, 2019a). We draw on the results from this project to derive WASH infrastructure improvement costs to enhance resilience against climate hazards. This project used reduction in damage probability as a measure of improvements in the resiliency of the system. Key water and sanitation infrastructure components are considered: reservoirs (open and storage tanks), water treatment plants (potable water and wastewater), distribution pipes, sewage network emissaries, water conveyance systems (canals), and drainage systems. For each of these components, Tables **Error!**

ranging from US$0.60/m^3 for brackish water to US$1.00/m^3 for seawater. The cost estimates for these alternative options were taken from the final report of the World Commission on Dams (WCD) (Sutherland and Fenn, 2000), with additional information from Zhou and Tol (2005). Based on these estimates, Ward et al. (2010) used US$0.30/m^3 as the global average cost of for alternative adaptation options and applied this cost as a backstop measure to cases where the cost of supplying water from reservoir storage exceeded US$0.30/m^3. Applying this methodology at the global level implies that in regions, such as MENA, where costs of reservoir storage capacity expansion are quite high and so desalination is emerging as a popular adaptation option, the actual costs of adaptation are likely to be higher than what is reported here, whereas in other regions such as parts of Asia where decentralized rainwater harvesting is gaining in popularity, the actual costs of adaptation are likely to be lower. At the global level, we expect these differences to average out, but at regional and country level these estimates must be used with caution.

Reference source not found. and 2 show details of engineering design and quality improvements to make these facilities more resilient to extreme weather shocks, and the normalized costs of reducing the damage probabilities under two major climate hazards that can compromise WASH facilities: floods and wind damage. We weighed the normalized improvement cost for each component by its share in the overall costs for water and sanitation systems. We then used the weighted sum of these costs as the infrastructure resilience cost markup.[18]

Table 1. Cost of Water Infrastructure Improvement for Resilience

Type	Natural hazard		Critical system/component			Damage probability (resiliency index)			Normalised improve-ment cost	Cost share of component	Incremental cost
	Hazard	Intensity	Component	Engineering improvement	Quality improvement	Estimate Baseline	Improved	Normalised improved			
Reservoirs (impounding)	Flood	Large event	Embankment crest	Design for higher freeboard (taller structure)	Maintenance, drenching	0.2	0.05	0.3	0.05	0.15	0.0075
Reservoirs (storage tanks)	Wind	Large event	Elevated tank	Design for higher wind force	Keep tank full during storms	0.2	0.05	0.4	0.1	0.08	0.008
Water treatment plants	Flood	Large event	Pumping system	Elevating	Improve construction quality	0.5	0.2	0.5	0.05	0.34	0.017
Distribution pipes	Flood	Large event	Pipelines	Higher threshold for large pipe displacement	Keep the pipes filled with water to mitigate buoyancy effects	0.2	0.1	0.3	0.02	0.26	0.005
Water conveyance systems (canals)	Flood	Large event	Gates and locks	Use proper gates, dry channels adjacent	Periodic maintenance, construction inspection	0.1	0.02	0.2	0.15	0.16	0.024
Markup cost for adaptation											0.0617

Source: Miyamoto (2019a) and authors' estimates.

Table 2. Cost of Sanitation Infrastructure Improvement for Resilience

Type	Natural hazard		Critical system/component			Damage probability (resiliency index)			Normalised improve-ment cost	Cost share of component	Incremental cost
	Hazard	Intensity	Component	Engineering improvement	Quality improvement	Estimate Baseline	Improved	Normalise Improved			
Sewage network emissaries	Wind	PGWS = 90 mph	WTP building	Roof-wall connection retrofit and building envelopes replacement	Apply higher level of QA (assuming (E) is on standard level)	0.04	0.03	0.7	0.15	0.01	0.0015
	Flood	FID = 3.3 ft.	Pump station	Elevation and watertight barrier installation		0.08	0.01	0.1	0.4		
Wastewater treatment plants	Flood	Large event	Pumping system	Elevating	Improve construction quality	0.5	0.2	0.5	0.05	0.99	0.0495
Markup cost for adaptation											0.051

Source: Miyamoto (2019a) and authors' estimates.

[18] The cost share for each component of the system was taken from EPA (2023) and City of Corpus Christi (2018) for water systems, and from Jardim et al. (2012) for sanitation systems.

V. Electricity (SDG 7)

A. Background

The first target of SDG 7 advocates for countries to “ensure access to affordable, reliable, sustainable and modern energy for all,” with its primary indicator measuring the extent of electricity access by the population. Gaspar et al. (2019) devised a methodology—updated in Carapella, Mogues, Pico-Mejía and Soto (2023)—to estimate countries’ additional spending needs to provide universal electricity access. Increasing electricity consumption could, however, also have important repercussions for the climate, in particular if countries do not modify their electricity generation approaches. Consequently, the second SDG 7 target calls for substantially increasing the share of energy that is generated using renewable sources, to support the 2015 Paris Agreement’s overarching goal to limit the increase in the global average temperature to well below 2^{o} C above pre-industrial levels. Meeting this goal would require cutting global greenhouse emissions between 25 to 50 percent below current levels by 2030 (Parry et al., 2021). If countries fail to raise the ambition of their climate goals above the Nationally Determined Contributions (NDCs), the world will not attain the objective of the Paris Agreement (IRENA, 2020).

Countries will then need to reconcile the increase in electricity consumption consistent with achieving universal access and in tandem with income growth, with the goal of reducing greenhouse gas emissions. Possible avenues to addressing both objectives include increasing energy efficiency and favoring low-carbon energy sources. For both, one of the most effective measures is to adjust carbon pricing. The International Carbon Price Floor (ICPF) scenario (IMF, 2022) would contain the increase in temperature to 2°C, with high-, middle-, and low-income countries implementing a minimum carbon price of US$75, 50, and 25 per ton, respectively. This implies that countries in these income groups will, respectively, reduce CO_2 emissions by 38, 29, and 24 percent by 2030, as compared to a business-as-usual scenario. Altering the energy mix to achieve these reductions, especially within a short time frame, could have expenditure implications, which need to be assessed. On the other hand, the fact that costs of renewable sources have been declining drastically over the past several years is also a helpful development and should be accounted for in the cost estimates (IRENA, 2022).[19]

While ramping up electricity production can have consequences for global warming, the reverse is also true: Extreme weather events, such as floods or hurricanes, may in turn severely impact the electricity network, disrupting supply and affecting livelihoods, and these weather effects are exacerbated by climate change. Climate risks could then potentially limit the capability of a country to reach the first target of SDG 7 and sustain it beyond the SDG end-year of 2030. Electricity infrastructure that is not resilient may thus harm businesses

[19] The global weighted levelized cost of solar photovoltaic has decreased by 88 percent between 2010 and 2021 (IRENA, 2022).

and individuals: Unreliable power infrastructure costs firms globally US$38, 82, and 65 billion a year arising from reduced utilization, sales losses, and the need for self-generating electricity, respectively, and costs to households amount to about US$15 billion (Hallegatte, 2019b). Adaptation and proper maintenance of infrastructure is then crucial to help countries in achieving the SDGs, proving cost-effective in the long run. In this section, we estimate the additional spending needs to reach the SDG 7 target for universal access to electricity while accounting for these climate mitigation goals and adaptation needs.

B. Methodology

1. Additional Electricity Spending to Adhere to Mitigation Goals

a. Costs arising from a change in the energy mix

The starting point in accounting for mitigation goals when costing the electricity target of SDG 7 is the derivation of the energy mix in 2030 that is consistent with containing global warming to 2°C above pre-industrial global average temperatures by mid-century. To be on track toward this goal, global greenhouse gas emissions must be reduced by 25 to 50 percent below current levels by 2030. One path to achieving this is by getting carbon pricing right.[20] The Climate Policy Assessment Tool (CPAT), developed by the IMF's Fiscal Affairs Department and the World Bank, contains projected electricity generation in 2030 that would be consistent with mitigation goals as outlined in the ICPF scenario. CPAT also includes data on current levels of electricity generation. Both the 2030 projections and the current data are at the country level and disaggregated by source of energy.[21] Based on this, we derive the electricity mix for the current period and for 2030:

$$G_{xit}^{sh} = \frac{G_{xit}}{\sum_x G_{xit}}$$

where G_{xit} is the amount of electricity generated with energy source x in country i at time $t = \{t_0, T\}$, and G_{xit}^{sh} is the percent (share) of total electricity generated that originates from source x. To ensure that the additional spending needs to meet mitigation goals are comparable with the expenditure to achieve universal electricity access that do not account for climate goals—see updated estimates in Carapella, Mogues, Pico-Mejía and Soto (2023)—we apply the current and 2030 shares, i.e. $G_{x,i,t0}^{sh}$ and G_{xiT}^{sh}, respectively, to the current and 2030 levels of electricity consumption, $con_{i,t0}$ and con_{iT}, respectively, which were derived in the estimation that does not account for climate goals, i.e., considers only the additional cost of meeting the SDG 7 target of universal access and electricity consumption in line with economic growth. This produces consumption estimates by energy source:

[20] Detailed information on the appropriate policy mix to achieve the objective of cutting GHG emissions is explained in Black et al. (2022).

[21] There are nine energy sources contained in CPAT—four non-renewables (coal, oil, natural gas, nuclear) and four major renewables (biomass, wind, solar, and hydroelectricity) in addition to a residual category of renewable energy sources (mostly geothermal).

$$con_{xit} = G_{xit}^{sh} \cdot con_{it}$$

where $t = \{t_0, T\}$. To calculate the additional spending accounting for climate mitigation objectives, we first create a counterfactual: what the level of electricity consumption from each energy source would be in 2030 in the absence of mitigation measures (a business-as-usual scenario, *bau*), i.e., if the current energy mix were retained into the future:

$$con_{xiT}^{bau} = G_{x,i,t0}^{sh} \cdot con_{iT}$$

The additional spending arising from meeting mitigation targets, $cost_i^M$, would then be given by the higher costs related to additional electricity consumption from some (e.g., renewable) sources, net of the savings stemming from lower consumption of other (e.g., nonrenewable) sources, in particular, those that would decrease under the carbon pricing regime of the ICPF scenario:

$$cost_i^M = \sum_x [(con_{xiT} - con_{xiT}^{bau}) \cdot UC_{xiT}]$$

where UC_{xiT} is the country- and energy-source-specific investment unit costs in 2030 in US$/kW, estimated by CPAT, including generation, transmission, and distribution costs.[22]

b. Electricity storage for the additional renewable energy

Increasing the production of renewable electricity, especially when generated with variable renewable energy (VRE)—primarily, wind and solar—raises the need for storage technologies. Given the intermittent nature of VRE, to achieve better efficiency and use of these sources, it becomes necessary to build storage facilities that will allow to dispatch electricity during the stretches of time when these plants are not active, so as to be able to satisfy periods of higher demand.

IRENA (2020) estimates the global needs for storage capacity in 2030 to absorb the increase in VRE electricity generation in a scenario that would keep the global rise in temperatures below 2° Celsius. We first derive a global storage-to-capacity ratio, SCR_t, from the IRENA Transformative Energy Scenario, for the current period and for 2030.[23] We then multiply the ratio by the VRE consumption, to obtain the storage needs:

$$S_{it} = con_{it}^{vre} \cdot SCR_t$$

[22] Generation of investment cost is country- and energy-source-specific in CPAT, while for transmission and distribution a value of 0.04 US$/kWh, or 350.4 US$/kW, is added to each investment unit cost.

[23] IRENA estimates that in 2030, VRE global capacity needed would be 5,753 GW and storage consistent with this increase in capacity is 745 GWh. Thus, the storage-to-capacity ratio is: $SCR_{2030} = \frac{745}{5,753} = 0.129$.

The cost associated with the additional storage needed in 2030 is assessed on the basis of the levelized cost of storage (LCOS):[24]

$$cost_i^S = \left(S_{iT} - S_{i,t0}\right) \cdot LCOS$$

2. Making Electricity Networks Climate-Resilient

Besides additional expenditure arising from mitigation, adaptation costs also accrue when accounting for climate change in achieving a strong performance on the electricity target of SDG 7. This arises from the fact that adverse weather events exacerbated by climate risks will increasingly bear on the functioning of electricity networks. Examples of adaptation include the installation of flood protection walls around a thermal plant, or the use of materials with greater fatigue life for wind turbine blades. To calculate these additional adaptation costs, we apply estimated energy and climate event mark-ups to make existing energy plants climate resilient from Miyamoto (2019a). The authors use the reduction in damage probability as a proxy for improvements in the electricity plants. Table 3 shows the additional percentage (share) increase in cost to make unimproved energy facilities resilient to severe floods and winds.

Table 3. Cost Markup to Make Energy Facilities Resilient to Natural Hazards

Energy facility type	Natural hazard		Critical system/component			Normalized cost					
	Hazard	Intensity	Component	Engineering improvement	Quality improvement	Baseline			Improvement		
						Comp.	QI	Total	Comp.	QI	Total
Thermal power plants (coal, gas, oil)	Wind	100 mph	Building structures stacks	Stiff braced structures, Helical strake	Welding quality control, inspection, testing	0.90	0.10	1.00	0.08	0.02	0.10
	Flood	2- to 3-ft. inundation	Entire facility	Floodwall, sheet piling	Ensure water tight construction, inspection	0.90	0.10	1.00	0.02		0.02
Hydropower plants	Flood	Large rainstorms, 200- to-500-year flood	Spillways, dam crest overtopping	Increased spillway capacity	Proper drenching, underwater inspection,	0.90	0.10	1.00	0.02	0.01	0.03
Solar farms	Wind	100 mph	Uplift support	Proper anchorage support for platform	Ensure tested components uses, perform random sampling	0.90	0.10	1.00	0.12	0.03	0.15
Wind farms	Wind	Design wind 70 to 100 mph	Blade	Optimize blade configuration Use material with higher fatigue life Conservatism in	Periodic inspection, report any crack initiation on blades or connections	0.90	0.10	1.00	0.04	0.01	0.05
Nuclear power plants	Flood	Large event	Reactor ground, cooling towers, buildings	Improved dike construction, extreme event flood design	Shutdown drills, document review, including geotechnical, hydrological, and construction documents	0.90	0.10	1.00	0.04	0.01	0.05
Substations	Wind	Design wind 70 to 100 mph	Elevated components	More robust components	Testing, inspection	0.90	0.10	1.00	0.15	0.05	0.20
	Flood	2- to 3-ft. inundation	Transformers, buildings, ground mounted equipment	Elevate components	Review construction reports, inspections	0.90	0.10	1.00	0.08	0.02	0.10
Transmission and distribution lines	Wind	Design wind 70 to 100 mph	Tower	Use steel, concrete or composite towers Use vibration dampers	Construction inspection, Use tested components	0.90	0.10	1.00	0.15	0.05	0.20

Source: Miyamoto (2019a).

[24] The LCOS, measured in US$/kWh, represents the present value of the total costs (including for example operation and maintenance, cost of debt, and capital spending to install the storage facility) incurred over the lifetime of a storage technology. The cost used in the analysis is the average of PNNL's estimated unit costs for four major battery technologies (lead acid, vanadium, lithium ferrophosphate (LFP), and nickel manganese cobalt (NMC)). We account for decreasing cost of battery storage in 2030, by taking the projection of storage battery cost for 2030 from Cole and Karkamar (2023), then apply it to the LCOS estimated by PNNL.

These mark-ups, α_x, are applied to the current generation investment costs from CPAT, to obtain unit costs of making facilities for energy source *x* in country *i* climate-resilient:

$$UC_{xit}^{A} = UC_{xit} \cdot (1 + \alpha_x)$$

This assumes that the whole existing and new electricity network needs to be adapted to become climate resilient.[25] Then, total adaptation costs for country *i* are:

$$cost_i^A = \sum_x con_{xit} \cdot (UC_{xit}^A - UC_{xit}) = \sum_x con_{xit} \cdot UC_{xit} \cdot \alpha_x$$

The total additional cost accounting for infrastructure resilience and mitigation goals in reaching the SDG 7 target for electricity is, then:

$$cost_i^{CL} = cost_i^M + cost_i^S + cost_i^A$$

This cost is added to the 2022 estimates of expenditures to align electricity consumption with economic growth and the goal of universal access, in order to obtain the annual additional pending in percent of GDP to reach the SDG taking into account climate change related goals and needs.

VI. Road infrastructure (SDG 9)

A. Background

1. Key Types of Extreme Events Affecting Road Infrastructure

Adequate access to road infrastructure is foundational to economic development. SDG 9 calls for developing quality, reliable, sustainable, and resilient infrastructure by 2030, to support economic development and human well-being. The first indicator (SDG 9.1.1) focuses on road access for rural populations. Roads, like other transportation infrastructure, is a multi-decadal asset. However, the design of roads is based on historical climatic conditions. As these climate conditions are changing, current road networks are becoming highly vulnerable to various climate related hazards. The UN's Sendai Framework for Disaster Risk Reduction called for improved risk management when building and managing infrastructure networks, and adaptation costs for infrastructure assets have been one of the largest components of total adaptation costs in past estimates (UNFCCC, 2007).

Due to its spatial distribution, road infrastructure is exposed to a wide range of climate related hazards,

[25] This assumption makes the estimate an upper bound, since in some countries part of the current electricity network will already have been constructed to withstand climate-induced extreme weather events such as floods and storms.

including floods, cyclones, and landslides. Of these various hazards, floods are estimated to affect more people globally than any other type of natural disaster (Koks et al., 2019). Three major types of flooding can be distinguished: i) Fluvial or river flooding occurs when the water level in a river rises and overflows onto the surrounding banks, shores, and neighboring land. The water level rise could be due to excessive rain or snowmelt. ii) Pluvial or surface flooding is caused by heavy precipitation events combined with other changes in land use and land cover. Pluvial flooding can take place in any location, including areas with no water bodies. iii) Coastal flooding is the inundation by seawater of land areas along the coast. Common causes of coastal flooding are high tide, tsunamis, and storm surges. In addition to floods, in mountainous regions, frequent and intense rainfall events due to climate change also cause landslides, which can damage roads and lead to service interruption that may last for months.

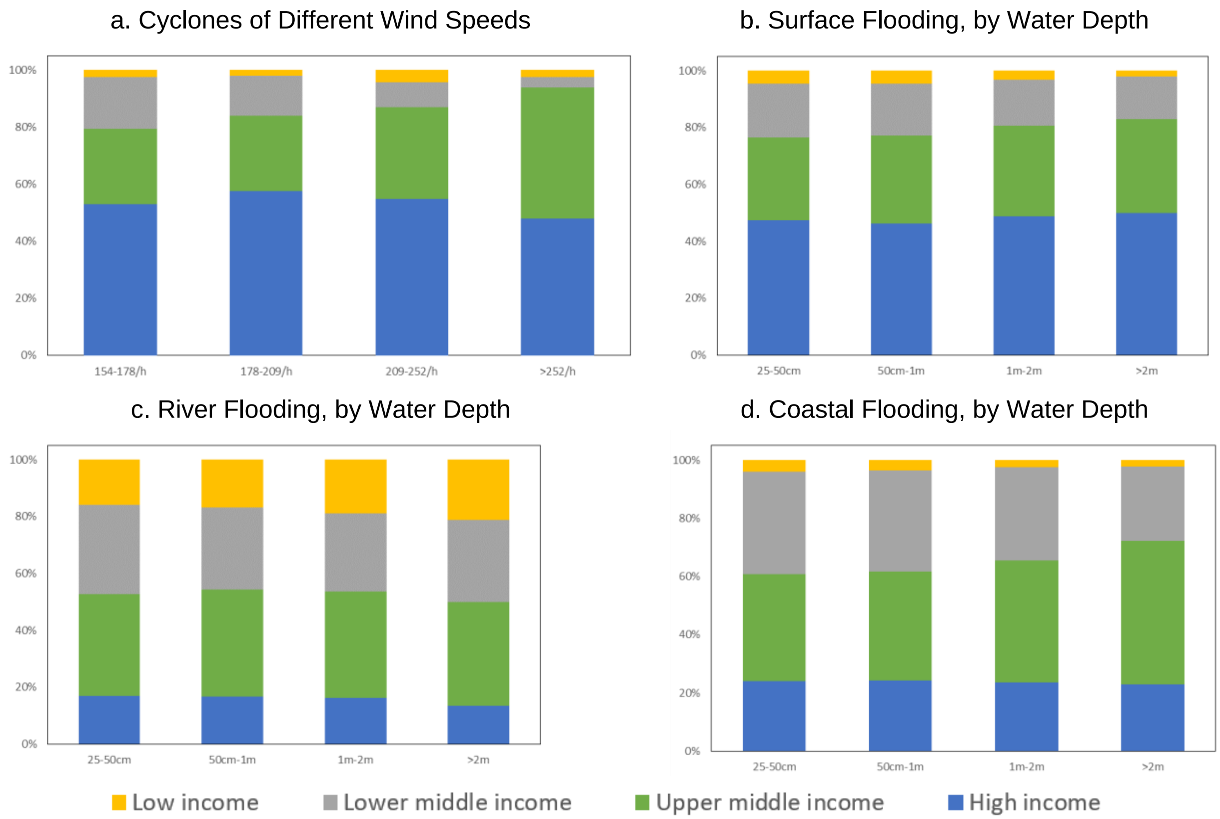
Another important climate related hazard are tropical cyclones, which is a generic term for a low-pressure system that forms over tropical waters (25°S to 25°N) with thunderstorm activity near the center of its closed, cyclonic winds (NOAA, 2023). Cyclones with winds exceeding 74 mph are designated as hurricanes (in the Atlantic or East Pacific oceans) or typhoons (in the northern west pacific). A recent review of more than 90 peer-reviewed scientific articles found that “the proportion of severe TCs [tropical cyclones] (category 3 & 5) has increased recently, possibly due to anthropogenic climate change” (Knutson et al., 2021). This proportion of intense tropical cyclones is projected to increase further, bringing a greater proportion of storms having more damaging wind speeds and more extreme rainfall rates that are likely to exacerbate the vulnerability of existing road infrastructure.

2. Exposure of Road Infrastructure to Climate Related Hazards

High income countries have the greatest total length of transport infrastructure, accounting for almost half of the global total, followed by upper middle-income countries accounting for almost a quarter. Low-income countries’ road infrastructure is particularly exposed to river flooding (Figure 5). Road systems in high- and upper-middle-income countries contend the most with the consequences of tropical cyclones, given high hazard areas such as the Caribbean, the US Gulf and east coast, eastern China, South Asia, and Japan (Koks et al., 2019). For river and coastal flooding, their vulnerability is reduced due in part to higher flood protection standards.

Figure 5. Exposure of Road Infrastructure to Cyclones and Floods

(Percent of total road infrastructure)



Source: Authors' calculations based on data from Koks et al. (2019).

3. Assessment of Climate Risks for Road Infrastructure and Policy Design

A key factor in assessing the risks of these climate hazards for infrastructure design and policy is the probability of occurrence of a hazard—often referred to as the return-period. Thus, for example, a return-period of 100 years refers to a hazard with a 1-in-a-100 chance of occurring in any given year. This is also referred to as 1 percent annual exceedance probability (AEP). Transportation infrastructure is most often designed to be able to resist a certain return-period rainfall event. When the probability of a rainfall event exceeds this design threshold, the excess water may adversely affect the transport assets, often leading to disruption of usage and reduction in asset life. In the 1960s, the United States government decided to use the 1 percent AEP as the basis for its national flood insurance program, considered a fair balance between protecting the public and managing costs (USGS, 2023). With climate change, as these hazards are expected to become more intense and frequent, the norm was recently revised upwards to "500-year floods," or AEP of 0.2 percent (FEMA, 2022). These norms vary widely across countries for different infrastructure assets, depending on geo-morphological and climatic factors as well as societal preferences for risk tolerance and fiscal and financing constraints.

A recent study found that that the design return-periods of nearly 88 to 95 percent of global transportation assets will become shorter in 2050 relative to the historical period of 1971–2000, with an average decrease of 25 percent under the mean of RCP4.5 and RCP8.5 scenarios, respectively (Liu et al., 2023). Given this reduction in return-periods, transportation infrastructure may become less reliable than anticipated, and thus investments will be required to upgrade the design standards and provide the same level of protection under the changed climatic conditions.

B. Methodology

The methodology for estimating the cost of enhancing the climate resilience of the road network required to provide broad access to roads by 2030, as called for in the first indicator of SDG 9, entails estimating the extent of road infrastructure exposure to various hazards, and applying an appropriate cost markup that reflects needed improvements in the resilience of exposed roads. Data used in Koks et al. (2019) reflect subnational level estimates of the exposure of primary, secondary, tertiary and other roads[26] to different intensities and probabilities of occurrence of natural hazards (cyclones and three types of flooding) that are exacerbated by climate change.[27] These data are generated using OpenStreetMap (OSM) and global hazard maps. The intensities of the extreme weather events included in the data are measured in scientifically established hazard bands. For flooding events, these bands are defined in terms of the depth of submergence, while for cyclones they are defined by bands of wind speed.

Let L_{ipj}^{rz} denote the length *L* of road-type *r* (primary, secondary, tertiary, and other) in country *i* exposed to a hazard *z* (fluvial flood, pluvial flood, coastal flood, or cyclone) that occurs with probability *p* (return-period 10, 20, 50, or 100)[28] and is of intensity *j* (for flooding measured by the depth of water: 154-177cm, 178-208 cm, 209-251cm, or ≥ 252cm, and for cyclones measured by the wind speed: 154-177km/h, 178-209 km/h, 209-251 km/h, or ≥ 252 km/h). We determine the maximum length of road type *r* in country *i* that is exposed to different intensities *j* and probabilities of occurrence of hazard *z*, and then sum the lengths of road exposed to the four types of hazards:

$$L_i^r = \sum_z \left(\max_{j,p} L_{ipj}^{rz} \right)$$

Having derived the total length of each road-type *r* in country *i* that is exposed to climate hazards, we then

[26] Primary roads are defined as all major highways and trunk roads, secondary roads as all major provincial and subnational roads, and tertiary roads as important local roads, often linking secondary or primary roads with each other.

[27] Other climate related hazards, such as landslides, are not included in this analysis due to the limited availability of consistent global data.

[28] The dataset also includes return-periods of 200, 500 and 1,000 years. However, we did not consider these higher return-periods (which denote very low risk levels) given that road design standards in most countries are based on 50 year or lower return-periods (see Koks et al., 2019, Supplementary Table 7).

estimate the costs of improving the resilience of these exposed roads. Hallegatte et al., 2019 (a, b) and Miyamoto (2019a) assess how resilience of different infrastructure assets can be improved through engineering solutions and the associated costs. For instance, they estimate that by providing barriers and increasing the drainage size, the flood damage probability of secondary and tertiary roads can be reduced by half, at an additional 3 percent of the replacement cost.[29] However, these studies do not provide estimates of the cost markup for making primary and other roads resilient to climate hazards. For these latter two types of roads, we thus rely on Koks et al. (2019), who estimate the cost markup to be 2 percent of the replacement costs. We apply these cost markups to the unit road construction costs used in Carapella, Mogues, Pico-Mejía and Soto (2023).

The above estimation of costs pertains to upgrading existing road infrastructure exposed to climate hazards. It is also necessary to upgrade new infrastructure investments being made to expand road coverage to achieve SDG 9. Hallegatte et al. (2019b) establish, based on their cost-benefit analyses, that there is economic value in investing in resilient infrastructure and it is more cost effective to incorporate resilience upgrades to new infrastructure than to repair or retrofit *ex post* after damage. However, we do not have estimates on the spatial details of exposure of different future (to-be-built) road assets to the various climate hazards. As an approximation, we apply the average markup of 2.5% for road assets from Hallegatte et al. (2019a), to estimate the costs of upgrading new road investments to make them climate resilient.

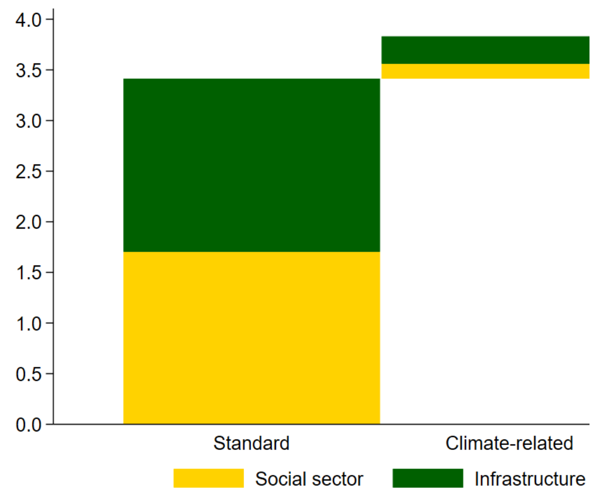
VII. RESULTS

A. Global climate-adjusted estimates of additional spending in selected SDGs

The updated estimates (Carapella, Mogues, Pico-Mejía and Soto, 2023) of additional SDG spending needs based on the Gaspar et al. (2019) methodology that do not account for climate risk costs—for simplicity, we will refer to these as the "core" SDG cost estimates—show that the world will need to spend an additional annualized 3.41 percentage points of GDP in 2030 to achieve a strong performance in the selected SDGs for human and physical capital development, which is equivalent to US$3.02 trillion. Our analysis finds that spending to attend to critical climate mitigation goals and adaptation needs in the five SDG areas adds another annualized 0.41 percent of global 2030 GDP, or US$358 billion, to result in total additional climate-adjusted SDG spending needs of 3.82 percent of GDP in 2030 (Figure 6). While the climate-related addition to the costs is smaller than the initial core development spending needs, this is nevertheless a nontrivial augmentation to the SDG resource requirements. The distribution of global additional expenditure between spending to bolster human and physical capital development shifts, with a bigger share of the climate-related expenditure going to meeting SDG needs in the infrastructure-intensive sectors.

[29] Miyamoto (2019a) remarks that secondary and tertiary roadways are not susceptible to damage from direct wind.

Figure 6. Additional Core and Climate-related Costs for Selected SDGs



Source: Authors' estimates.

B. The distribution of additional climate-related costs across country groups

1. Additional Climate-related Costs to Meet Selected SDGs, relative to GDP

We also consider the distribution by income group of the core and climate-related additional expenditure needs in the selected Goals. LIDCs experience, relative to their GDP, the largest augmentation to their SDG costs (Figure 7a). The core needs, already high at 16.12 percent of 2030 GDP, rise by another 1.04 percent of GDP, to a total of 17.17 percent of GDP.[30] This rise is more modest for EMEs, by 0.54 percent of their GDP to a total of 5.29 percent of GDP.[31] While AEs' additional climate-related SDG spending is by far the lowest, at 0.15 percent of their GDP, it should be noted that it is sizeable relative to the additional core spending of 0.17 percent of AEs' GDP. In the regional distribution, the full climate-adjusted additional resource needs are highest for SSA at 20.54 percent of GDP—1.15 percent of GDP higher than the core expenditure needed ignoring climate risks (Figure 7b).

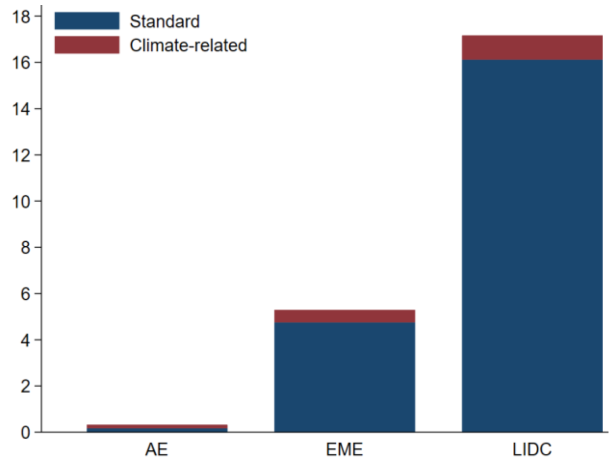
[30] The core and climate-related figures are reported here rounded to the second digit after the decimal, hence may not add up to the total shown here.

[31] These estimates are only somewhat higher than those in IMF (2023a), which estimates additional annual climate-related spending needs for LIDCs and EMEs of 0.7 and 0.4 percent of GDP. It should be noted that these estimates only account for adaptation needs, while our results additionally reflect mitigation spending needs in the selected SDGs.

Figure 7. Additional Climate-adjusted Expenditure Needs

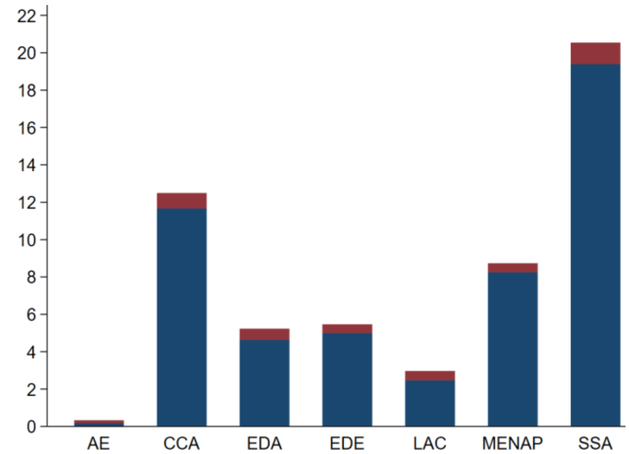
(Percent of GDP)

a. By Income Group



Source: Authors' estimates.

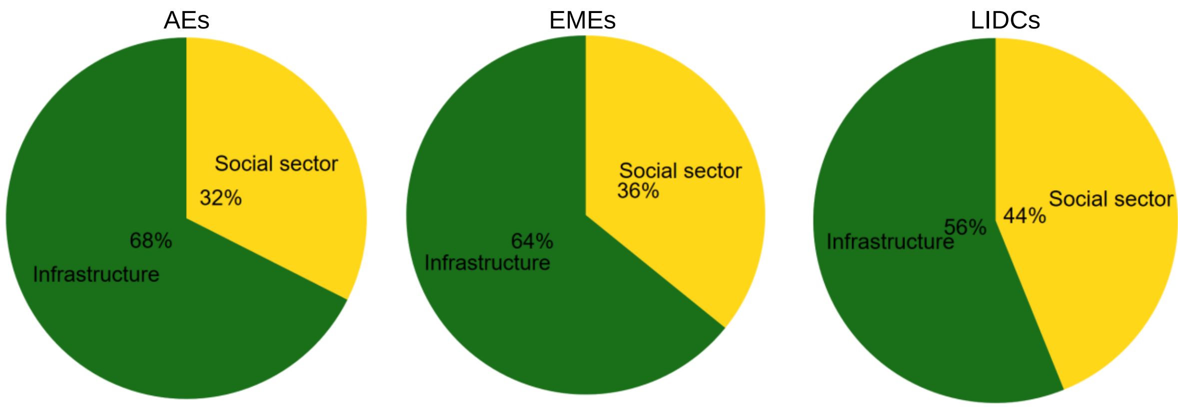
b. By Region



Source: Authors' estimates.

A breakdown of climate-related SDG spending by sector reveals the relatively large weight of this spending in the infrastructure sectors, amounting to the majority in each income group (Figure 8). Furthermore, the higher the income group is, the larger the weight of climate-related resource needs in the infrastructure sectors of electricity, roads, and water and sanitation. Ensuring resilience of the education and health sectors are sizeable for LIDCs, while additional mitigation and adaptation costs related to the electricity sector loom large for EMEs (Figure 9).

Figure 8. Share of Social Sector and Infrastructure Sector Climate-related Expenditure Needs in Selected SDGs

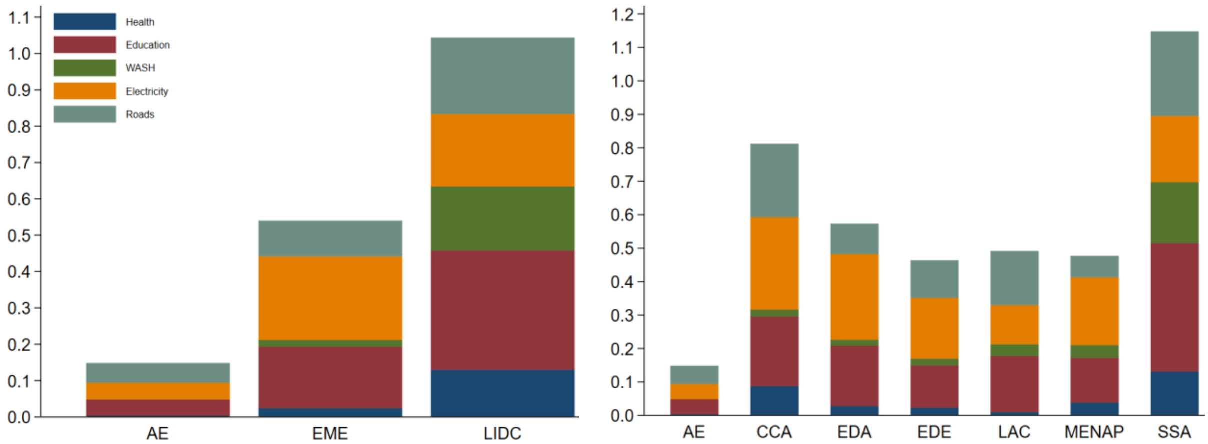


Source: Authors' estimates.

Figure 9. Additional Climate-related Spending Needs in Sectors of Selected SDGs

(Percent of GDP)

a. By Income Group b. By Region



Source: Authors' estimates. Source: Authors' estimates.

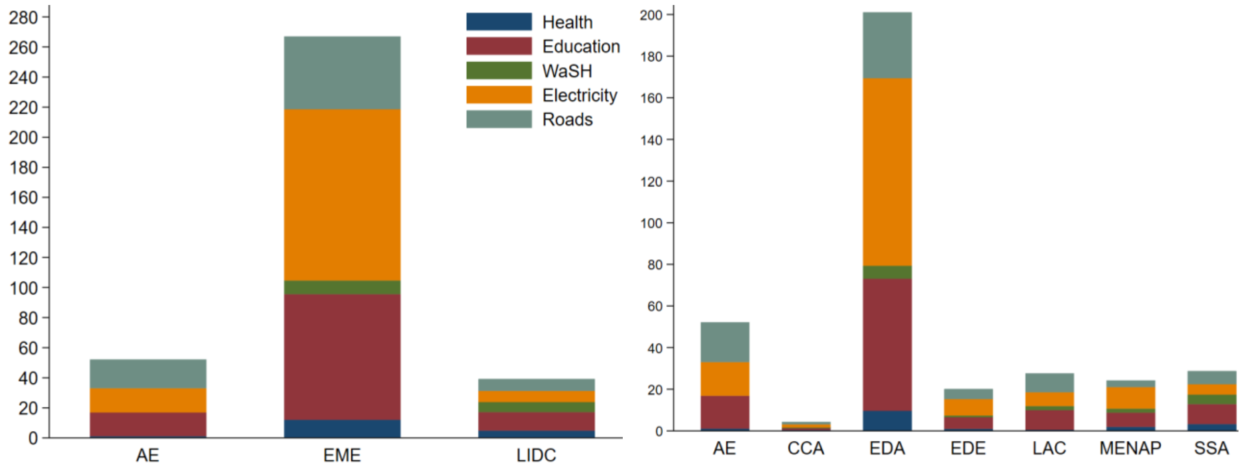
2. Additional Climate-related Costs to Meet Selected SDGs, in Absolute Terms

While the burden of both the core and climate-related cost relative to GDP rises sharply with income group, as was shown in Figures 7a and 9a, in absolute terms it is EMEs who will expend the most in the aggregate—both to deliver basic services in social and infrastructure sectors, as well as to make these sectors adequately resilient to climate risks and meet emissions goals (for the latter, see Figure 10a). This is driven by needs of large Asian emerging economies (Figure 10b). In addition to the US$2.35 trillion that are needed in EMEs to deliver a good performance on the core targets of the selected SDGs, US$267 billion would be added to address climate risks in these sectors. LIDCs, in contrast, face US$644 billion of climate-adjusted additional SDG costs in 2030, increasing from the core estimate of US$605 billion. AEs have not only the lowest additional climate-adjusted SDG expenditure needs relative to income, but also in absolute terms (US$112 billion, of which US$52 billion is climate-related). LIDCs' climate needs are somewhat lower in absolute terms than those of AEs, and the composition of these needs differs importantly, as discussed earlier.

Figure 10. Additional Climate-related Spending Needs in Sectors of Selected SDGs

(US$ billion)

a. By Income Group b. By Region



Source: Authors' estimates. Source: Authors' estimates.

Caution is warranted when comparing expenditure needs across the literature—given important differences in scope considered, methodology, temporal range to which the costs apply, etc. Nonetheless, it is worth mentioning that our estimates are not out of range with that of other recent studies. For example, Rozenberg and Fay (2019) find that low- and middle-income countries can achieve infrastructure SDGs while staying on track to meet the 2°C goal with annual spending of an additional 4.5 percent of GDP. While lower than our study's EME climate-augmented cost estimate of 5.3 percent of GDP, the latter also includes non-infrastructure needs in health and education, which are not captured in Rozenberg and Fay (2019). (On the other hand, they additionally include infrastructure in other sectors such as agriculture). Hallegatte et al. (2019) estimate that the additional cost of making infrastructure climate-resilient amounts to 3 percent of the overall investment needs in low- and middle-income countries. Our estimates arrive at an addition of approximately 6 and 10 percent of climate-related costs on top of the core SDG needs, in the case of LIDCs and EMEs, respectively. Again, when noting our higher estimates, it should be kept in mind that our climate cost analysis is neither limited to adaptation, nor to infrastructure. Our results are also broadly in line with figures published in a recent IMF blog, Gaspar, Mansour and Vellutini (2023), who estimate that emerging markets and developing economies need $3 trillion annually through 2030 to finance their development goals and the climate transition. The lower estimate in the blog (compared to our 3.8 percent of global GDP) relates to a number of methodological and scope differences, including the fact that that their analysis does not include AEs nor China, and the climate related costs focus on adaptation only rather than both adaptation and mitigation as in our study. Bhattacharya et al. (2022) arrive at an estimate (incremental needs of US$3.5 trillion by 2030) similar to ours. However, it is important to note that here too there are several methodological variations with our study. Our estimates of additional costs in the energy sector are not directly comparable with those in the IMF's Global Financial Stability Report (IMF, 2023b) and in IEA (2023), in several respects: The latter reports focus on gross investments, while our analysis considers net additional investment (i.e., the difference to maintaining the current energy mix). Furthermore, our paper is only concerned with the electricity sector rather than with other uses of energy. The respective papers can be consulted for more details on their approach.

VIII.Summary and Conclusion

The urgency and scale of the climate crisis necessitates a reassessment of the resource allocation required for the attainment of core targets of selected SDGs in the areas of health and education for human capital development and access to critical infrastructure such as roads, electricity, and water and sanitation. With the world now more than half-way toward the deadline for reaching the SDGs, it is critical to understand not only the core resource needs for achieving a high performance in key SDG targets related to human and infrastructural development but also the additional costs associated with tackling climate goals within these SDGs. This study thus extends the scope of previous work (Gaspar et al., 2019; Carapella, Mogues, Pico-Mejía and Soto, 2023) by incorporating the spending to address mitigation goals and adaptation needs within the health, education, and selected infrastructure sectors.

Our findings underscore the considerable additional spending required to achieve selected SDGs while factoring in climate risks. The world will need to allocate an additional 3.8 percent of GDP by 2030 towards these goals, a figure that includes an additional sizeable 0.4 percent of global GDP to render the SDG sectors resilient and support global emission reduction objectives. The distribution of additional expenditure is set to shift, with a somewhat greater proportion of climate-related expenditure being directed towards the resilience of infrastructure sectors. Across income groups, LIDCs face the most significant climate-related SDG costs relative to GDP—on top of the fact that these countries already face the largest additional expenditure requirements to meet core SDGs. EMEs, on the other hand, bear the highest costs in absolute terms. This differential burden underscores the need for a context-specific approach to resource allocation, as well as the necessity for substantial international cooperation and financial support. It should be noted that the climate-related spending needs in the SDGs of focus in this paper should not be viewed merely as burdens, but rather as investments necessary to avoid greater future private and fiscal costs that would arise from damage to infrastructure and people from climate-related shocks.

While this study contributes to our understanding of the spending implications of climate change for the attainment of SDGs, conducting a cost-benefit analysis of mitigation and adaptation measures goes beyond the scope of this study. As such, other research could compare climate-related expenditure needs to costs associated with delaying action now and addressing climate damage in the future beyond 2030; doing so would highlight prominently the value of meeting the climate-related spending needs earlier. Also, while this paper focuses on the mitigation and resilience needs that are specific to social sector SDGs (3 and 4) and key targets in infrastructure SDGs (6, 7, and 9), future work can carry out a more comprehensive assessment of meeting climate goals of other SDGs, including goals like SDG 13 that is centrally focused on climate change.

This paper also does not seek to address the distinct but no less important issue of how to finance the climate-related expenditure needs to strengthen progress toward the SDGs of focus. IMF (2023a) concludes that establishing a carbon price floor, complemented by instruments to correct other market failures, can contribute to both reducing emissions in but also well beyond the SDGs considered in this paper, while also generating revenue to meet the large adaptation challenge. Other IMF analysis of four case study countries established that progress in the core SDGs—even without accounting for climate-related costs—will require governments to pursue an ambitious reform agenda, mobilize domestic revenue,[32] and improve spending efficiency,[33] to increase national resources to meet two of the four countries' SDG spending needs, and even then, the SDGs would only be achieved with a delay in those countries (Benedek et al., 2021). The latter study also finds that increasing official aid (mostly by advanced economies) to the United Nations target of 0.7 percent of gross national income (GNI) would largely cover the financing gap of the four case countries. To finance climate change costs, the Copenhagen Accord signed at COP15 of the UNFCCC in 2009 stipulated that developed countries would provide scaled-up climate finance to developing countries, reaching $100 billion a year in 2020. The IPCC notes that a key agreement was that climate financing should be 'new and additional' and not at the cost of SDGs, and doing otherwise may raise the vulnerability of a population for any given level of climate shocks (IPCC, 2022).[34] Our estimates of these additional costs of climate change at the global level are a first step towards understanding the financing needs for the SDGs under consideration.

Finally, we recognize that there are potential interdependencies among the various SDGs, which are explored in several recent research studies (Laumann et al., 2022, Swain & Ranganathan 2021, Sachs et al., 2019, Griggs et al., 2017) and policy fora (UN High level Political Forum on Sustainable Development, 2022). These studies point to both synergies and tradeoffs among these goals. These interdependencies, estimated using non-linear measures of conditional dependence and represented using network analysis, were found to vary significantly among different income groups (Laumann et al., 2022) making it difficult to generalize at the global level. Overall, the findings call for the need to strengthen mechanisms for policy coherence, including ensuring that short-, medium- and long-term plans are all aligned towards the same aims. Yet these studies also recognize that in the current situation, policymakers generally operate within the constraints of their sector-specific annual budgets and key performance indicators (KPIs) that only address their thematic expertise, so at the ground level the potential interdependencies are not fully accounted for. Future work can extend this paper by working towards a model that accounts for these interactions and can support efforts towards policy coherence.

[32] Benedek et al. (2021), for example, suggest that in one of their case study countries—Pakistan—vigorous tax policy and revenue administration reforms could help raise tax revenue ratio by more than 3 percentage points of GDP over four years.

[33] Efficiency gains can dramatically increase outcomes in key SDG areas considered in our study. For example, raising a country's value of the indicator that is the strongest determinant of health spending efficiency to the 75th percentile of the country's income group would on average result in life expectancy rising by 3.4 years of life in LIDCs, and by 2.2 years in EMEs (Garcia-Escribano, Juarros and Mogues, 2022). And removing public investment inefficiencies would increase infrastructure output by 55 percent (Kapsoli, Mogues and Verdier, 2023).

[34] CARE Denmark recently suggested that most of climate finance may not be "new and additional," and that instead it is largely development finance that is being diverted towards climate change action (Hattle and Nordbo, 2022).

Appendix

Table A1. Number of countries in the initial and updated SDG costing studies

	Gaspar et al. (2019)	Carapella, Mogues, Pico and Soto (2023); Aggarwal, Carapella, Mogues and Pico (2023)
Total	155	173
By Income group		
AE	34	33
EM	72	83
LIDC	49	57
By region		
CCA	8	8
EDA	16	27
EDE	15	12
LAC	25	30
MENAP	20	18
SSA	37	45

Source: Authors' calculations.
Note: Advanced Economies are considered as a country group in the IMF regional classification, but figures for AEs are just stated once under income groups, instead of being repeated.

Table A2. Summary of the additional core and climate-related SDG expenditure needs in current and previous studies

(Percent of GDP)

	Paper:	Gaspar et al. (2019)	Carapella, Mogues, Pico and Soto (2023)	Aggarwal, Carapella, Mogues and Pico (2023)	
	Description:	Standard estimates, previous	Standard estimates, updated	Climate-related estimates	Climate-adjusted: Standard (updated) and climate-related, combined
Global					
Total		2.4	3.4	0.4	3.8
Social sectors		1.2	1.7	0.1	1.9
Infrastucture sectors		1.2	1.7	0.3	2.0
By Income group					
Total	AE	0.0	0.2	0.2	0.3
	EM	4.1	4.8	0.7	5.5
	LIDC	15.4	16.1	2.0	18.2
Social sectors	AE	0.0	0.1	0.1	0.2
	EM	2.0	2.3	0.4	2.7
	LIDC	8.3	9.0	1.4	10.5
Infrastucture sectors	AE	0.0	0.1	0.1	0.2
	EM	2.1	2.5	0.4	2.8
	LIDC	7.1	7.1	0.6	7.7
By region					
Total	CCA	8.8	11.7	1.5	13.2
	EDA	4.6	4.7	0.8	5.4
	EDE	3.4	5.0	0.6	5.6
	LAC	1.4	2.5	0.7	3.2
	MENAP	5.5	8.3	0.7	8.9
	SSA	18.8	19.4	2.4	21.8
Social sectors	CCA	5.4	6.3	1.0	7.3
	EDA	2.3	2.3	0.4	2.7
	EDE	1.7	1.7	0.2	2.0
	LAC	0.4	0.6	0.4	1.0
	MENAP	3.2	5.5	0.4	5.9
	SSA	8.8	9.9	1.8	11.7
Infrastucture sectors	CCA	3.3	5.4	0.5	5.9
	EDA	2.3	2.4	0.4	2.8
	EDE	1.7	3.3	0.3	3.6
	LAC	1.0	1.9	0.3	2.2
	MENAP	2.3	2.7	0.3	3.0
	SSA	9.9	9.5	0.6	10.2

Source: Authors' calculations.

Note: Advanced Economies are considered as a country group in the IMF regional classification, but figures for AEs are just stated once under income groups, instead of being repeated under regions.

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