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The Socioeconomic Impact of Climate Change in Developing Countries in the Next Decades

A REVIEW

Philip Kofi Adom

Abstract

The Socioeconomic Impact of Climate Change in Developing Countries in the Next Decades: A Review provides a discussion of future trends as established in the literature on the interaction between socioeconomic indicators and projected future climate change scenarios. It enhances our understanding of future predicted patterns of climate change effects in the coming decades and the need for climate-resilient interventions. There is a significant body of literature on climate impacts on GDP per capita and crop yield in developing countries. However, impacts on farmland value, water resources, and energy security have received much less attention. Across sectors, countries, and regions, the most vulnerable groups were found to be disproportionately affected, and the impact is predicted to be larger in the long term than in the medium term. There are feasible adaptation and mitigation options, but these need to be developed and designed to reflect local peculiarities or contexts. Generally, the review report indicates the need for urgent actions to be undertaken, especially in the most vulnerable countries, if we are to stand a chance of averting or minimizing the menace of climate change in the future.

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The Socioeconomic Impact of Climate Change in Developing Countries in the Next Decades: A Review

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List of abbreviations

CGEM-IAM	computable general equilibrium modeling–integrated assessment modeling
CI	confidence interval
CVD	cardiovascular disease
GDP	gross domestic product
GENESIS	Global ENvironment and Ecological Simulation of Interactive Systems
HadCM	Hadley Centre Coupled Model climate simulation
HAPPI	half a degree additional warming, prognosis, and projected impacts
IPCC	Intergovernmental Panel on Climate Change
NDC	nationally determined contribution
OECD	Organisation for Economic Co-operation and Development
PV	photovoltaic
RCP	Representative Concentration Pathway
SSP	Shared Socioeconomic Pathway
UI	uncertainty interval
UN SDG	United Nations Sustainable Development Goal
Wm^{-2}	watts per square meter

Executive summary

Climate change is a growing threat to the world. Extreme weather events, rising temperatures, and changing rainfall patterns will become more frequent, posing a particular threat to developing countries, where social, economic, and political institutions are fragile. If the menace of climate change is not addressed, the socioeconomic problems of developing countries, particularly in Africa, will deepen and erode the gains made in development in the last decades.

This concern has spurred research interest in the effects of climate change on socioeconomic indicators. The purpose of this report is to gather evidence and analyze the effects of climate change on socioeconomic indicators in developing countries. This approach involved reviewing previously published studies on the topic, with a focus on developing countries. As these studies differ in methods, initial conditions, and model assumptions, it is difficult to draw comparisons. At best, we can analyze the general patterns observed. Specific focus is given to the following socioeconomic indicators: GDP per capita (income), agricultural productivity (food security and farmland value), hunger and undernourishment, poverty, health, water resources, and energy security. The following are the major highlights of the report.

1. **Economic loss due to climate change will be significant in the long term in developing countries.** Although there are varied perspectives on the effects of climate change on economic growth, the balance of evidence indicates that economic growth will decline more in developing countries – in Africa in particular – and in the long term. For Africa, studies have suggested moderate economic loss in the medium term, before 2050, but beyond this period, economic loss due to climate change will increase. The literature has suggested a mean decline of 7.12 percent of GDP in the long term. Even within Africa, the most vulnerable subregions and countries will be disproportionately affected. Western and eastern Africa will suffer the most due to global warming. Country-level projections have suggested much greater economic losses, ranging from –11.2 percent to –26.6 percent of GDP in the long term, in the most affected regions of Africa. While at the global level, negative effects from warming become more pronounced at around 2 degrees Celsius, smaller temperature increases could cause significant negative impact on socioeconomic indicators in developing regions, including Africa. The spatial and temporal variations in the evidence indicate the need to consider the local context when developing climate adaptation and mitigation interventions.
2. **Food insecurity and declining farmland value are major future concerns under climate change scenarios.** There is consensus in the literature on the effects of rising temperatures on crop yields and farmland value. The impact will be disproportionately higher in developing regions such as Africa and in the long term. Regional studies in Africa and Central and South America have suggested an extremely large reduction in agricultural/crop production yield. In Africa, it ranges from –2.9 percent in 2030 to –18 percent in 2050. In Asia and North America, the evidence is not conclusive, with estimates of impact varying from highly negative to highly positive. However, rainfed crops will suffer the most, with

irrigated crops proving to be more resilient to climate change (but still only partially). Climate change is expected to reduce the value of farmland in Africa in the long term by 36 to 61 percent. At 2°C global warming, the risk of climate-caused food insecurity would be severe, which might increase the incidence of malnutrition, undernourishment, and micronutrient deficiencies.

3. **Millions of people are at risk of extreme hunger and undernourishment under climate change scenarios.** With declining crop yields due to climate change, a significant number of people in Africa will be at risk of severe hunger, malnutrition, and undernourishment. In Africa, more than 200 million people risk suffering from extreme hunger in the long term.
4. **Poverty is likely to deepen in Africa in the future.** With the significant projected decline in crop yields due to climate change, households that work in the agricultural sector are likely to face decreased incomes and a rise in poverty. We find that in Africa, climate change is likely to cause crop revenue loss of approximately 30 percent and a rise in poverty of between 20 and 30 percent, compared to a no-climate-change scenario.
5. **The numbers of water-distressed areas and areas at risk of flood are likely to increase in the future due to climate change.** Climate change affects hydrological cycles, in turn affecting freshwater and groundwater levels, the levels and timing of stream flow, and levels of precipitation. Studies project a moderate decrease in water security in Africa. Overall, climate change is likely to push more than 50 million people in Africa into water distress. For other regions, such as Asia and North America, the literature has suggested impacts that vary between a moderate decline and an increase in water scarcity. More severe droughts and flooding in the future are also expected to deepen food security concerns and increase the number of people displaced due to flooding.
6. **Energy security is likely to suffer in the future under climate change scenarios.** Climate change affects the energy system. Generally, there is some consensus on the increasing effects of climate change on energy demand, but the literature is divided on the effects of climate change on energy generation potential. While there is agreement on the damaging effects of climate change on the generation potential of solar, wind, and thermal power, the impact of climate change on hydropower and bioenergy generation is not clear.

In summary, important interactions exist between climate change and socioeconomic indicators. However, some vulnerable economies and regions will be disproportionately affected by climate change in the future. While the socioeconomic impact of climate change is predicted to be moderate in the medium term, the impact is predicted to be large in the long term. The impact is moderate below 2°C of global warming but becomes larger beyond 2°C. This indicates that limiting global warming below 2°C would improve socioeconomic outcomes, including poverty; incomes; energy security; health; and water, sanitation, and hygiene. Across studies, there is evidence of spatial and temporal variation in the effects of climate change on socioeconomic indicators. This indicates the need to consider the local context in the design of climate adaptation and mitigation measures and take urgent actions to reduce the impact of climate change on Africa's future development, in particular.

1. Introduction

There is evidence of recent rising trends in extreme weather events, warmer temperatures, and changing rainfall patterns (Valenezuela and Anderson, 2011). The latest Intergovernmental Panel on Climate Change (IPCC) report asserts that the average temperature of the Earth has increased by 1.09°C between 2011 and 2020, above the levels observed in 1850–1900 (IPCC, 2022). The IPCC estimate that there is a 50 percent chance that in the near term, global warming, even under a very low greenhouse gas emissions scenario, will reach or exceed 1.5°C (IPCC, 2022).

According to the IPCC report, extreme weather events that occurred on average once every 10 years within the period 1850–1900 are now likely to occur 2.8 times every 10 years – and that figure is expected to rise to 4.1 times every 10 years should global warming hit 1.5°C. These climate-induced events can result in severe floods and droughts (IPCC, 2022).

The rising frequency and intensity of extreme weather events has significant impacts on the natural world. For example, it reduces biodiversity, with evidence of population collapse and local extinction (del la Fuente and Williams, 2022). The interdependence of climate, biodiversity, ecosystems, and human societies (IPCC, 2022) indicates that climate change will also have a far-reaching adverse impact on humanity. Studies such as those by Batten (2018) and the IPCC (2014) have demonstrated the multiple impacts of climate change on broad sectors of the economy, human health, and water resources. Climate change is impacting food systems (von Braun et al., 2023; Miron et al., 2023; Abeysekara et al., 2023; Chandio et al., 2023), economic growth (Dell et al., 2012; Arndt and Thurlow, 2015; Adom and Amoani, 2021; Duan et al., 2022; Meattle et al., 2022), health (Abbas et al., 2023; Astone and Vaalavuo, 2023), labor productivity (Valenzuela and Anderson, 2011), water systems (Han et al., 2022; Bibi and Tekesa, 2023), energy markets (Tahir and Al-Ghamdi, 2023), and poverty (Hertel et al., 2010).

Among these worrying trends of rising climate change impacts in general is the concern of a particularly devastating impact on developing economies, which have very low capacity to adapt to the adverse effects of climate change (Tol, 2018; Stern, 2007). The purpose of this study is to document evidence and trends in the literature on climate change impacts across different socioeconomic factors in the next decades, with a focus on developing economies.

Although all economies, regions, communities, and sectors are exposed to the impacts of climate change, the impact is not homogeneous (Signe and Mbaye, 2022). Developing economies with low adaptive capacity risk experiencing greater impacts than developed economies (Cline, 2007; Stern, 2007; Ludwig et al., 2007; Bowen et al., 2012; Tol, 2018). With weak food, water, health, and infrastructural systems in developing economies, climate change may impoverish millions. Beyond placing the United Nations Sustainable Development Goals (UN SDGs) out of reach (Ludwig et al., 2007), climate change may reverse previous gains in development in these economies.

The heterogeneous impact of climate change implies that no one-size-fits-all strategy exists that can help developing countries limit negative outcomes. There is also little consensus about the relative and absolute scale of impacts across sectors and development outcomes (see, for example, Arndt and Thurlow, 2015; Baarsch et al., 2020; Nelson et al., 2010), which introduces uncertainty in policy design and weakens efforts to combat climate change. This study takes stock of the existing knowledge and trends in climate change impacts across different socioeconomic and political factors in the hope of helping those who are designing climate-resilient programs that are sensitive to context.

2. Methods and data

2.1 Review type and scoping strategy

Various studies have been conducted on the potential impact of climate change on different socioeconomic, environmental, and political factors in different contexts. The purpose of this section is to explain the boundaries for the studies included in this review. As the aim is to examine the trends and patterns in the literature on the subject, this study incorporates a desk literature review on the topic to establish the scope, trends, and patterns of the evidence gathered so far from a developing-economy context. Because the underlying assumptions for models predicting climate change impacts differ from one study to another, we are cautious in making comparisons across these studies. At best, it is safe to discuss the patterns and trends of impacts established in the literature.

The first step in this desk review was the identification of keywords. The keywords were of two broad types: climate change indicators and socioeconomic factors. For climate change indicators, the following keywords were used: *climate change, temperature, precipitation, carbon dioxide emissions*, and *pollution*. For the socioeconomic indicators, the following keywords were used: *economic growth, income, poverty, welfare, health, agricultural productivity, water resources, energy demand, energy supply*, and *energy security*. In the second step, we paired each of the climate change indicators with the socioeconomic indicators in the searches. Initially, these searches were broad, without limitation in terms of period or context, to establish the depth of existing research on the topic. The third step involved sorting the evidence gathered to focus on the essential studies. At this stage, some inclusion and exclusion criteria were established to help narrow the focus of the included literature while keeping in mind the key research question for this review. Table 1 shows the inclusion and exclusion criteria for this study.

TABLE 1. Inclusion and exclusion criteria for creating the database

Inclusion Criteria	
1	The context of the study includes at least one developing country.
2	The study adopts either a strictly quantitative or mixed approach in the assessment of the impact of climate change.
3	The study makes medium- to long-term predictions of climate change impacts.
4	The outcome of the examination includes one of the socioeconomic indicators identified earlier in this study.
5	The study contains a clear description of the methods and data used.
Exclusion Criteria	
1	The study is inaccessible either because it was not yet published at the time of review or due to subscription requirements.
2	The study adopts a strictly qualitative approach.
3	The study was published in a predatory journal or questionable outlet.

2.2 Nature of the study and data collection strategy

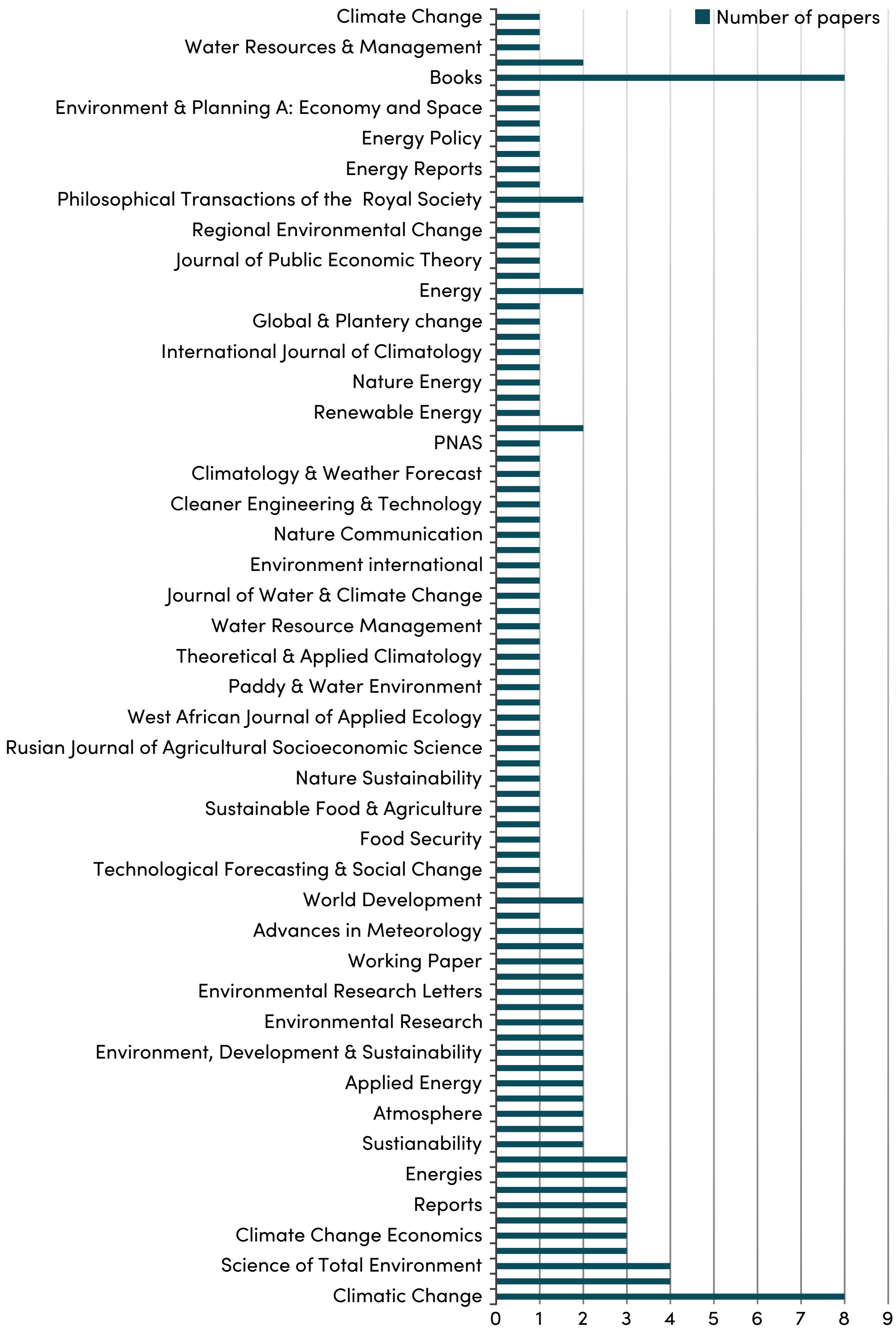
Different questions about climate change impact necessitate different approaches. This review has a strong bias toward measuring the future impact of climate change on socioeconomic indicators, so priority is given to studies with a strong quantitative orientation. Qualitative studies were not ignored entirely if efforts were made to quantitatively measure the impact of climate change. Thus, preference was given to either quantitative or mixed-methods studies.

Scopus, Google Scholar, and the Web of Science database were the primary search engines used for this review. Data from these sources were combined and sorted to eliminate duplicate studies. We also complemented these data using the bibliographies of the identified studies. Data from reports, books, working papers, and conference papers were also used.

2.3 Summary of the data

We gathered a total of 139 studies from 79 publication outlets, which were obtained from various search engines on climate-related impacts after applying the exclusion and inclusion criteria. A significant number of these studies are journal articles, with a few appearing as conference papers, reports, books, or book chapters, or working papers. There are no clear leading sources among the publication outlets, although some journals, such as *Climatic Change, Global Environmental Change*, and *Science of the Total Environment*, among others, published a few more studies than the others (see Figure 1).

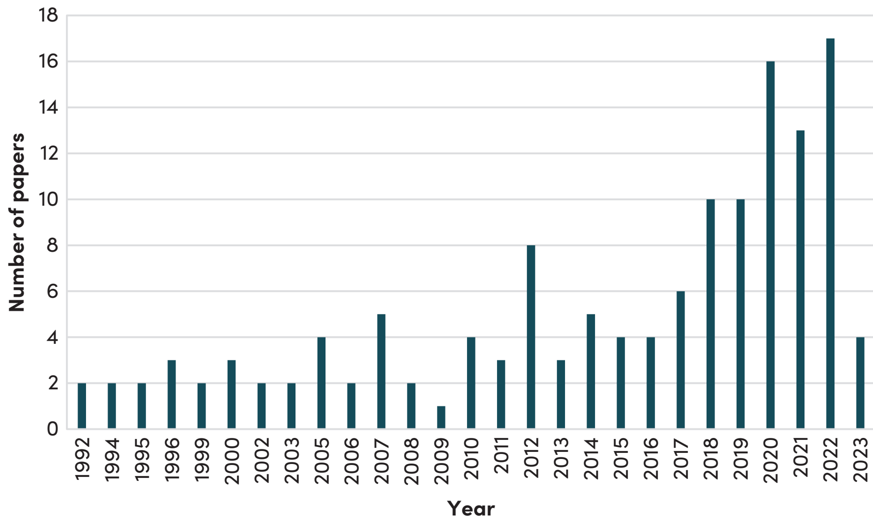
FIGURE 1. Distribution of studies by publication outlet



Source: Author's own construction.

In terms of the date of publication, the distribution seems skewed to recent years, with most of the papers being published after 2017 (see Figure 2). The years 2020 and 2022 recorded the highest publication numbers, followed by 2021, 2018, and 2019.

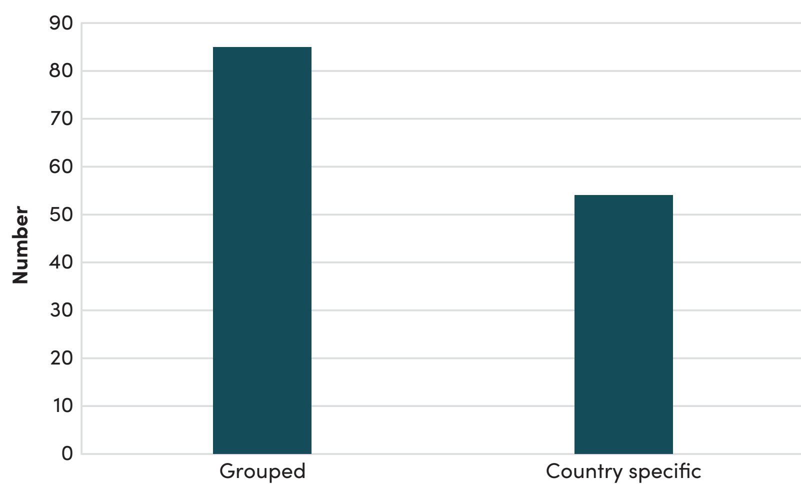
FIGURE 2. Distribution of studies by year of publication



Source: Author's own construction.

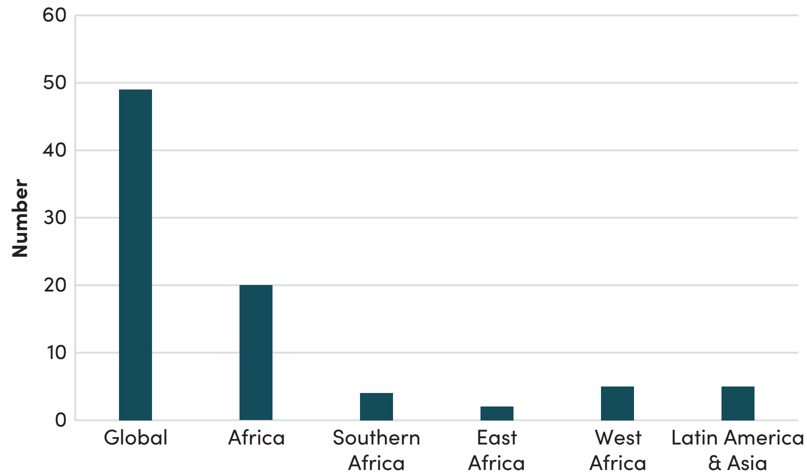
In terms of context, Figure 3 shows the distribution of studies by type: grouped and country specific. It is clear from the figure that most of the studies in this review (85) used group-level data, while the remaining studies used country-level data. Of the 85 studies that used group data, 49 used global data and the rest used regional- and subregional-level data (see Figure 4). Figure 5 shows the distribution of studies by specific country of focus. The greatest number of papers focused on India (8 studies), followed by China (7) and Ethiopia (4). Comparatively, the country-specific data plot shows that the focus, and thus the balance of evidence of climate change impacts, is biased toward Asia and Africa: 20 of the country-specific case studies, out of a total of 54 are from Africa and 34 from Asia.

FIGURE 3. Distribution of studies by context



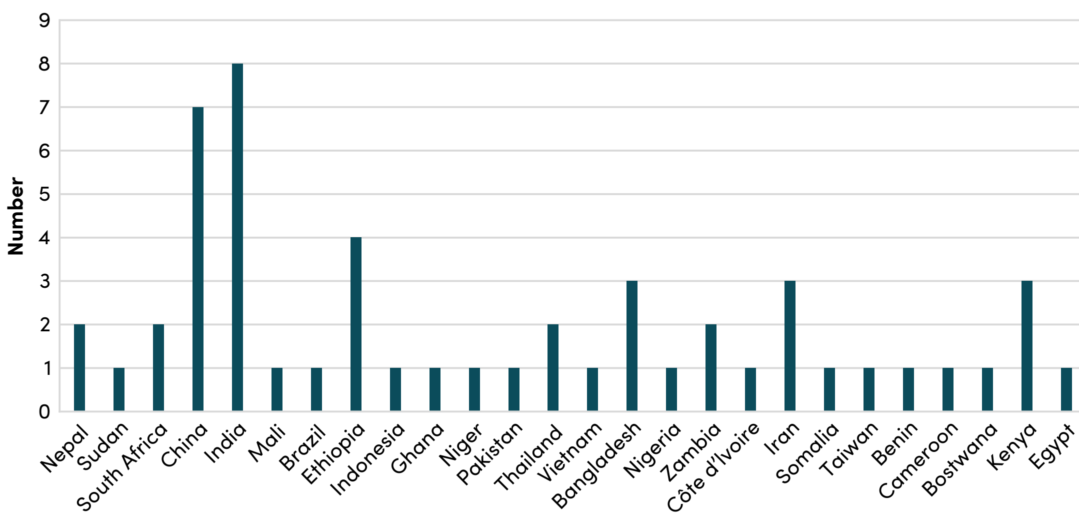
Source: Author's own construction.

FIGURE 4. Distribution of studies by data source



Source: Author's own construction.

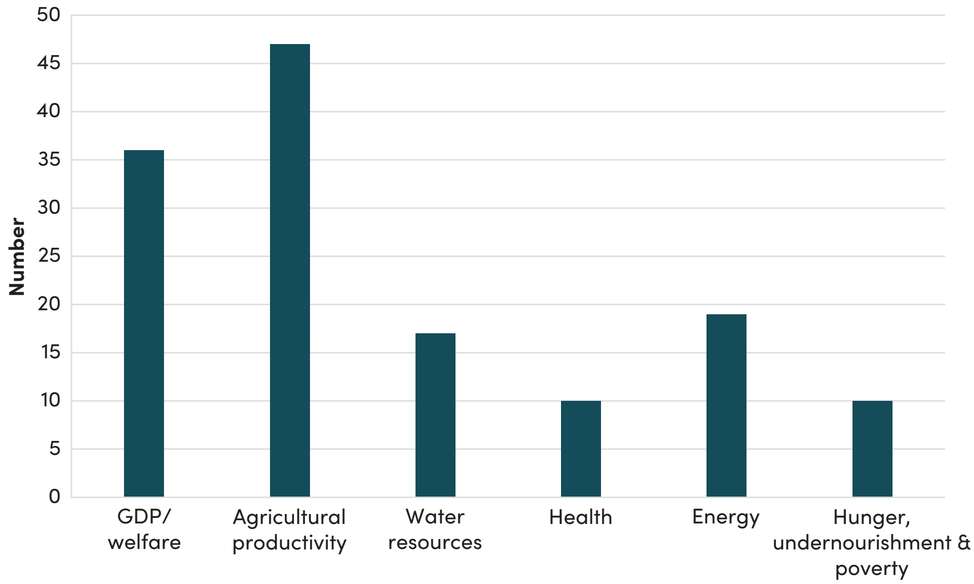
FIGURE 5. Distribution of studies by country of focus



Source: Author's own construction.

Finally, we plot the distribution of papers by theme (Figure 6). It is clear from the figure that the agricultural sector has received more attention in terms of climate change impact assessment than other sectors. As shown in the figure, 47 of the 139 total reviewed studies assessed the impact of climate change on agricultural productivity. Most of these studies on agriculture assessed the impact of climate change on food security measures, while the rest examined the implications of future climate change for farmland value. Developing economies depend heavily on the primary sector, which explains their high susceptibility to climate change impacts. This might also explain why there is a strong focus on the agricultural sector in studies on the future impacts of climate change. The next largest group of studies (36) are economy-wide assessment studies using GDP or other economy-wide welfare measures. The water and energy sectors also have a reasonable amount of evidence (17 and 19 studies, respectively) on how climate change impacts them. Studies on the effects of climate change on health, hunger, undernourishment, and poverty together total just 20.

FIGURE 6. Distribution of studies by theme



Source: Author's own construction.

3. Medium- to long-term impact of climate change in developing countries

3.1 Impact of climate change on economic growth and income

The economy–environment link has been well investigated, but the relationship remains shrouded in ambiguity because context, variability in temperature patterns, technological evolution, and countries' adaptive capacity, among other factors, play a significant mediating role. Since the early 1990s, when major concerns about the impact of climate change first arose, significant research has been conducted to assess the impact of climate change on economic output. Some important early studies include Cline (1992), Fankhauser (1992, 1995), and Tol (1995). These studies assessed, on the basis of literature, extrapolation, and guesswork, both the tangible and intangible damage of climate change if atmospheric carbon dioxide emissions double. Generally, these studies agreed that the impact of climate change on economic output would be negative but differed in terms of the magnitude of that impact. To date, there are still debates on whether the projected impact of climate change on economic outcomes is linear or nonlinear, and this introduces uncertainty in policy development.

Today, it is largely agreed that few countries will be able to escape the adverse effects of climate change, even though the impact of climate change on economies, or the benefits from adaptation, are not likely to be homogeneous across economies and sectors. Studies providing evidence of the nonlinear concave effect of climate change on economic growth have suggested that additional global warming, while stimulating growth in cooler areas, will reduce growth in hotter regions. Studies by Mendelsohn, Morrison, et al. (2000); Mendelsohn, Schlesinger, and Williams (2000); Stern (2006); and the IPCC (2014) have reinforced the fact that the impact of climate change on economic output is not uniform across world economies. Developing economies are at highest risk, whereas developed economies are more likely to experience gains.

Using global data, Burke et al. (2018) found that additional warming boosts growth in cooler regions but slows growth in warmer regions. This finding is confirmed by Diffenbaugh and Burke (2019) and Duan et al. (2022). A critical issue of concern is the uncertainty about the temperature threshold beyond which the negative impacts of climate change will be realized (i.e., optimum temperature). The current literature reports a median optimum temperature estimate of 13.1°C but a 5–95 percent chance that the optimum temperature will fall within the range of 9.7°C–16.8°C (Burke et al., 2018). However, because a greater share of world GDP is currently generated in temperatures higher than the median optimum temperature, a high level of uncertainty is associated with determining the optimum temperature, and thus substantial uncertainty exists regarding the magnitude of the impact of climate change.

In assessing the economic impact of climate change, various methods have been adopted in the literature, each with different strengths and weaknesses. For example, Nordhaus (1994) and Tol (1995, 2002a and b) used the enumerative approach, in which they rely on natural science studies to derive the physical effects of climate change. By its very nature, the enumerative method generates physically realistic results that are easily interpretable. However, there are major concerns about extrapolation. They include using economic values for other issues for climate concerns, using values from a limited number of locations to extrapolate to the world, and extrapolating from estimated recent past values to the remote future. There is probably substantial error associated with such extrapolations (Brouwer and Spaninks, 1999) and hence with the predicted impact of climate change on economic variables. Other studies also use statistical methods that rely on observational data to obtain estimates of climate change on economic variables. This allows the use of real-world observed data rather than extrapolated data. That said, an important limitation of this approach is the claim of causality – attributing observed differences across locations to climate change. Moreover, statistical methods often treat cross-sectional variation, and some aspects of climate change, such as carbon dioxide fertilization and the direct effects of sea level rise, as not exhibiting significant spatial variation.

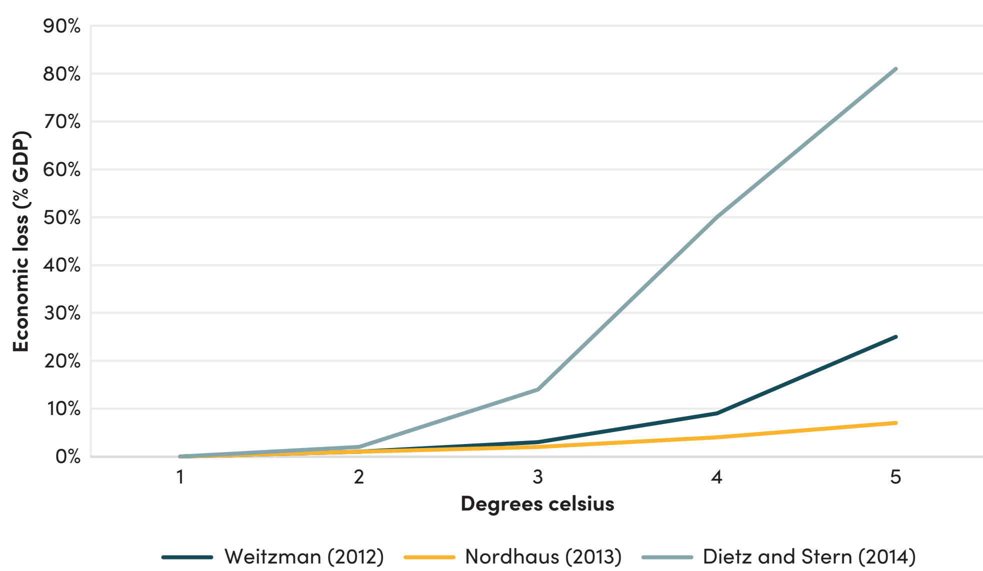
Different measures of welfare have been used in studies of economic growth. These include economy-wide measures such as per capita GDP, per capita consumption, productivity, capital depreciation, and poverty.

At the global level, major studies quantifying the future impacts of climate change include Mendelsohn, Morrison, et al. (2000); Mendelsohn, Schlesinger, and Williams (2000);

Stern (2006 and 2007); Weitzman (2012); Nordhaus (2013); and Dietz and Stern (2014). Mendelsohn, Morrison, et al. (2000) projected a cumulative loss of 0.3 percent of GDP for the global economy for 2°C global warming by 2060. While OECD countries will benefit, those in the rest of the world are likely to suffer losses in GDP. Mendelsohn, Schlesinger, and Williams (2000), in contrast, predicted cumulative damage of not greater than 0.1 percent of GDP by 2100 at 2.5°C. They also forecast that high-latitude countries will gain while low-latitude countries will lose. However, they note that beyond 2°C, the benefits accruing to high-latitude countries will diminish, while the losses experienced by low-latitude countries will increase. Stern (2006) also predicted a modest impact of climate change, of 0.2–2 percent of global GDP by 2100, under 2°C. However, beyond 3°C, countries will differ significantly in terms of their exposure to climate change risk. These assertions that the economic loss is probably significant beyond 2°C were not found in earlier papers by Fankhauser (1992) and Cline (1992), who projected that a temperature increase of 3°C and 2.5°C would reduce the world's GDP by 1.5 percent and 1.1 percent, respectively.

Figure 7 plots the global economic loss due to climate change under the different damage functions used by Weitzman (2012), Nordhaus (2013), and Dietz and Stern (2014) relative to the baseline cases (i.e. no climate change scenario) in 2100. It is clear from the figure that, among the three damage functions, the Nordhaus function provides the most optimistic picture of the impact of climate change on economic output. In both the Nordhaus and Weitzman models, the extent of economic loss is not distinctly different until we reach global warming levels of 3°C and beyond. The difference becomes wider beyond the 4°C limit. Under the Dietz and Stern model, the impact of climate change becomes significant after the temperature increase exceeds 2°C. All three studies suggest that the impact increases in developing countries but is small in developed economies. These studies indicate a tipping point of 2°C–3°C.

FIGURE 7. Economic loss due to climate change under different damage functions



Source: Covington and Thamotheram (2015).

Since these influential studies, other studies have estimated the future impact of climate change on global, regional, and national output. Pretis et al. (2018) assessed the global economic implications for 1.5°C and 2°C global warming targets by combining econometric techniques with the half a degree additional warming, prognosis and projected impacts (HAPPI) study to simulate the impact. Their results generally suggest that in terms of the growth effects of climate change, the impact is indistinguishable at 1.5°C and 2°C, albeit economic growth is more likely to slow at 2°C than at 1.5°C. In terms of the impact on projected levels of per capita GDP, the median impact is a decrease of 13 percent and 8 percent under 2°C and 1.5°C, respectively, relative to the base case. For all cases, the authors estimate that low-income countries will suffer more in terms of economic losses than high-income countries.

Burke et al. (2018) also assessed the economic damages associated with the temperature-increase thresholds of 1.5°C and 2°C using global data. To address the uncertainty involved in such an analysis, their study adopted bootstrapping methods and separate damage functions for each re-sample. The study suggests that there is a greater than 75 percent chance that if global warming reaches but does not exceed the 1.5°C threshold, the associated economic damages will be less than if global warming were to reach the 2°C threshold. Compared to the baseline, the reduction in economic output at 2.5°C–3°C warming by the end of the century (i.e., 2100) is likely to be as high as 10 percent by mid-century and between 15 and 25 percent in 2100, and more than 30 percent for 4°C global warming by 2100. If warming can be limited to 1.5°C, there is a greater than 60 percent chance that the accumulated global benefits might exceed US$20 trillion under a 3 percent discount rate.

At the country level, Burke et al. (2018) note that the distribution of benefits is not uniform. Countries in the tropics and subtropics are likely to experience per capita incomes that are 10–20 percent higher at 1.5°C than if global warming reaches 2°C by the end of the century. Comparative growth outcomes are likely to be negative for some high-latitude countries under 1.5°C relative to 2°C.

Kompas et al. (2018), in their global assessment of climate change impact, also reinforce the claim that beyond 2°C the impact of climate change on economic growth would be considerably greater in the long term (i.e., by 2100) than in the short and medium term and among developing economies than among developed economies.

Wang et al. (2020) conducted a study assessing global, regional, sectoral, and national economic losses from climate change. The study used three scenarios: business as usual (no further mitigation policy implemented in the future), Nationally Determined Contributions (NDC) [i.e., each country or region satisfy their NDC commitments for 2030], and a 2°C scenario. Projections indicate that by 2050, mean temperatures will be higher under business as usual, followed by NDC and then 2°C. To assess the climate impact, the authors adopted the computable general equilibrium modeling–integrated assessment modeling (CGEM-IAM) model. At the global level, across regions and sectors, the negative impact of climate change on GDP is higher under the business-as-usual scenario, followed by NDC and then 2°C. The authors estimate the global economic loss due to climate change under the business-as-usual scenario to be approximately US$305 billion a year (2011 US dollars) in 2030. However, by 2050, the economic loss will increase more than fivefold, to approximately US$1.628 trillion (approximately 0.79 percent of global GDP in that year). By 2050, economic loss due to climate change is estimated at US$1.398 trillion (0.68 percent of GDP) under NDC and US$822 billion under the 2°C scenario. Economic losses due to climate change are generally projected to be around 0.25 percent of GDP in 2030 for all sectors. However, in 2050, economic losses due to climate change will increase for all sectors and under all scenarios. Agricultural and energy-intensive sectors will be the hardest hit, while non-energy-intensive and service sectors will be the least-hit sectors. Under the business-as-usual scenario, economic loss in the agricultural sector due to climate change is projected to be approximately 1.2 percent of GDP for 2050. In terms of the regional distribution of the impact, the study found that developing economies will be the hardest hit by climate change. India and China will account for more than 40 percent of total global GDP losses by 2050. Other developing economies that will suffer the most include developing Southeast Asia (US$291 billion), the Middle East (US$128 billion), and Africa excluding South Africa (US$118 billion). These other developing economies will account for 33 percent of total global GDP losses in 2050. In sum, developing economies will account for approximately 85 percent of total global GDP loss, while developed economies will account for only 15 percent of global GDP loss in 2050.

Jiang et al. (2021) assessed the impact of rising temperatures on the economic growth of global economies from 2015 to 2100. The study focused on 12 regions, including Africa, Latin America, the United States, the European Union, China, India, and the Middle East. Three different climate scenarios were used: SSP5-RCP8.5, SSP2-RCP4.5, and SSP1-RCP2.6.[1] Climate change leads to economic loss, and this is highest under the SSP5-RCP8.5 scenario. Generally, the results showed that for all scenarios, developing economies will suffer more from climate change than developed economies. Among the developing economies, China, Africa, and the Middle East were the hardest hit by the advent of climate change. While China risks losing 10.7 percent, 4.6 percent, and 3.1 percent of its GDP to climate change under scenarios SSP5-RCP8.5, SSP2-RCP4.5, and SSP1-RCP2.6, respectively, for the United States the risk is much lower, at 3.2 percent, 0.8 percent, and 0.3 percent of output for the same scenarios. In Africa, the study revealed that irrespective of the scenario considered, the economic loss from climate change is likely to be minimal in the short and medium term (i.e., until 2050), averaging under 2 percent, but beyond this period the impact of climate change is likely to increase, with economic output loss ranging from 3 to 10 percent by 2100. These results indicate that poor and developing countries are more likely to be exposed to high socioeconomic risk due to climate change.

The above studies underscore the differing effects of climate change on economic output in different economic regions. Diffenbaugh and Burke (2019) assessed whether global warming is responsible

1 These scenario names combine the Shared Socioeconomic Pathways (SSPs) that they are based on with the associated Representative Concentration Pathways (RCPs) for greenhouse gas concentrations in the atmosphere, measured in watts per square meter of radiative forcing.

for increasing economic inequality through the lens of the effect of climate change on economic output. Their study revealed that global warming increases economic inequality globally, widening the gap between the per capita GDP of the top and bottom deciles of the global income distribution by 25 percent compared with the no-global-warming scenario.

Baarsch et al. (2020) examined whether climate change might delay income convergence in Africa. They found that inequalities are projected to decline at a slower rate in the high-warming scenario than in the baseline. This indicates that climate change might be delaying convergence in income in Africa and deepening economic inequality within the region.

Liu and Chen (2021) studied the future global socioeconomic risk related to drought, calculated as the product of three determinants: hazard, exposure, and vulnerability. The global population's risk related to drought was projected to be highest in 2046–2065 under scenario SSP3-RCP8.5, with a 63 percent increase in the number of people affected, compared with the base period (i.e., 1986–2005). The highest risk to GDP (4.29×10^{13} purchasing power parity $) was projected in 2046–2065 under scenario SSP1-RCP2.6, with the risk increasing 5.64 times compared to the base period. Regions with high socioeconomic risk are primarily concentrated in East and South Asia, midwestern Europe, the eastern United States, and coastal areas of South America. With climate change, inequality in the future socioeconomic risk of drought among countries is predicted to increase.

These global-level studies reveal some interesting facts about the economy–climate change relationship. First, for global warming above 2°C, future per capita output of world economies will be lower than no global warming case but not for all economies. Economies with weak infrastructure, poor technology, and low adaptive capacity will suffer the most, implying that any mitigation and adaptation measures will benefit these economies more. Second, the impact of climate change will be larger in the long term than in the short to medium term. Third, there is not a consensus about the optimal temperature as studies reveal a tipping point in global warming of either 2°C or 3°C.

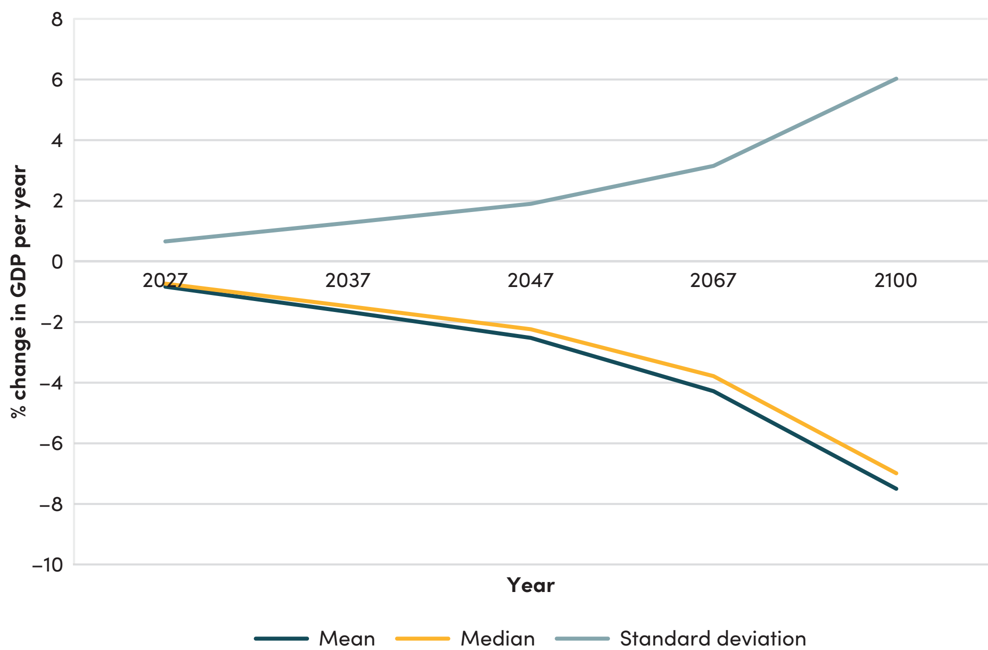
Evidence from country-specific and regional studies of developing economies also confirm the above narratives (von Braun et al., 2023; Signe and Mbaye, 2022; Burke et al., 2018; Ludwig et al., 2007). In Asia, country-specific studies have reported the negative impact of climate change on economic output. Cui et al. (2018) examined the effects of sea level rise on economic development and regional disparity in China under two scenarios: slow-onset sea level rise (S1) and sudden-onset storm surges (S2). Generally, the authors reported greater reductions in GDP under S2 than S1. If the sea level rise under S2 features sudden-onset extreme storm surges, coastal regions' GDP loss could reach 11 percent in 2050, compared to 1.97–2.39 percent under S1. Tianjin, Shanghai, and Jiangsu would have the most severe losses, with a decline of more than 20 percent in their individual GDP in 2050 under S2. Under S1, the GDP of the most affected areas, Guangdong, Jiangsu, and Hainan, would decline by more than 5 percent.

The story is not very different regarding the impact of climate change on economic output in Africa. Ngepah et al. (2022) conducted a study that sought to forecast the impacts of climate change on economic growth in South Africa over the 2030 and 2050 horizons. They noted that relative to the 1995–2000 levels, South Africa's economy would lose approximately US$1.8 billion due to climate change following the Representative Concentration Pathway of 4.5 Wm^{-2} radiative forcing (RCP4.5) scenario and US$2.3 billion following the RCP8.5 scenario by 2030. They further projected that by 2050, the losses would be US$1.9 billion and US$2.48 billion, respectively. These figures correspond to a national economic loss of 4.1 percent of GDP under RCP4.5 and 5.08 percent under RCP8.5 in 2030 and an economic loss of 4.11 percent under RCP4.5 and 5.19 percent under RCP8.5 in 2050. There is a very high economic cost to doing nothing about climate change (RCP8.5), and even the best plausible mitigation scenario (RCP4.5) still yields significant economic losses by 2030 and 2050.

Baarsch et al. (2020) studied the impact of climate change on incomes in Africa from 2015 to 2050. The study examined three dimensions of climate risk and disaster (exposure, vulnerability, and hazards) and used two scenarios (high and low warming). The study projected the adverse effects of climate change on GDP per capita growth in Africa, with western and eastern Africa expected to be the hardest hit. For these regions, the median estimate of the reduction in per capita GDP for the high-warming scenario compared with the low-warming scenario is more than 10 percent by 2050. In comparison, northern and southern Africa are projected to experience a median per capita GDP reduction of less than 10 percent, and Central Africa of less than 5 percent in the high-warming scenario. For all regions, the study revealed that the macroeconomic risk of climate change is twice as high in the high-warming scenario than in the low-warming scenario by 2050.

Kompas et al. (2018) found similar results, indicating that the severity of the impact of climate change on economic growth in Africa varies by subregion, degree of warming, and time span. The authors found regions such as western and eastern Africa to be the most likely to be hard hit by climate change. In terms of the degree of warming, the impact was negative for all scenarios but increased significantly once warming crossed the 2°C threshold. Figure 8 plots the projected mean and median climate change impact on GDP at 3°C global warming for different periods for Africa. The graph shows that even until 2050, the expected economic loss as a percentage of GDP due to climate change in Africa is marginal. Thus, in the next three decades, the GDP of African economies might not suffer that much due to climate change. However, beyond 2050, the loss in economic output due to climate change is projected to be large. By 2100, the percentage change in per capita GDP compared with a no-warming scenario could reach –7.5 percent. Dinar et al. (2012) also predicted a continent-wide reduction in GDP of between 6 and 100 percent by 2100 based on different climate models in Africa, compared to a no-warming scenario, except for two or three countries where the benefit of climate change is positive. The wide range in the scale of the potential impact is related to the varying temperature predictions produced by the researchers' different climate models. For example, in the most pessimistic scenario, the University of Illinois Urbana-Champaign predicts significant warming near the equator but moderate warming near the poles, whereas optimistic models such as Pollard and Thompson's Global ENvironment and Ecological Simulation of Interactive Systems (GENESIS) with dynamic sea ice model predict a modest rise in temperature near the equator but a larger rise in temperature in the temperate zones and near the pole zones.

FIGURE 8. Projected impact of climate change on GDP over time at 3°C for Africa



Source: Author's construction using data and original projections from Kompas et al. (2018).

Generally, from the African perspective, there is some consensus on at least the fact that climate change might drag down economic growth in the region, and this might risk pushing a significant number of people further below the poverty line, as compared to a no-warming scenario. Table 2 provides a summary of sample studies of climate change's impacts on economic output in Africa. These projected impacts are based on comparisons to average temperatures of the preindustrial period. Tol (2002a) assumed 1°C warming, Baarsch et al. (2020) assumed 8.5°C, Kompas et al. (2018) assumed 1°C–4°C, and the rest assumed 2.5°C. These studies' mean and median economic losses due to climate change are 7.12 percent and 4.82 percent, respectively, with a standard deviation of 5.86 percent. This shows a high degree of heterogeneity in the estimated impact of climate change on economic output in Africa. The estimates are quite heterogeneous even for the same global warming scenario of 2.5°C, with the projected loss in economic output ranging from 0.5 percent to 14.6 percent. These results revealed no tipping point in the economic effects of global warming for Africa: any warming from current levels is seen to reduce output.

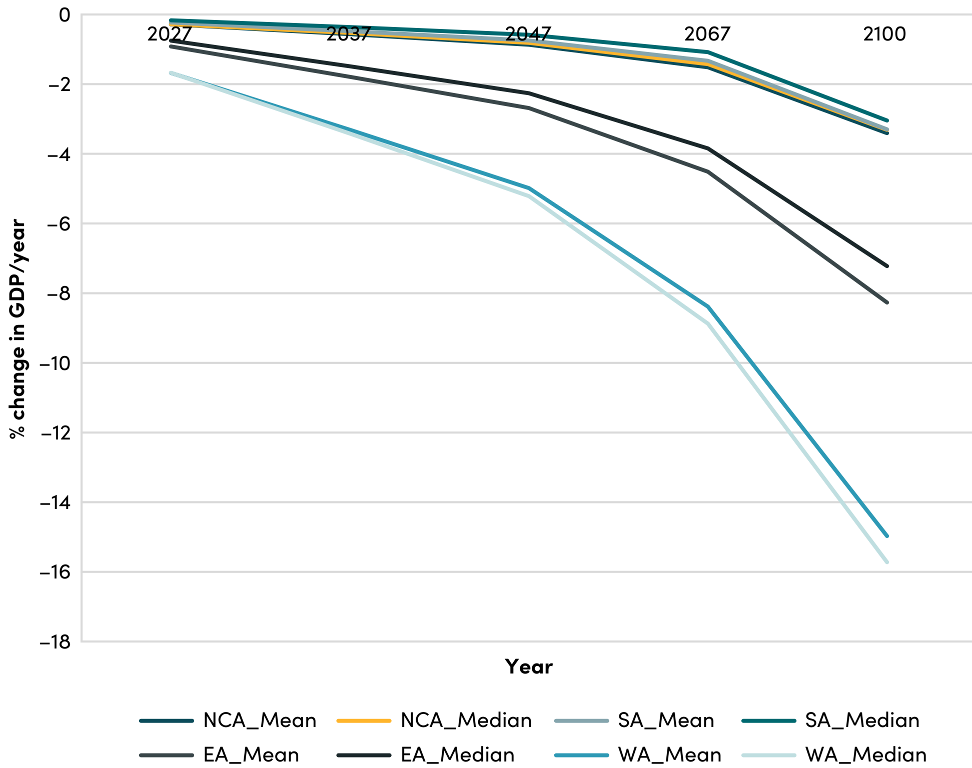
TABLE 2. Impact of climate change on economic output in Africa

Study Author	Year of Publication	Degree of Warming	Percentage Change in GDP	Forecast Year
Tol	1995	2.5°C	−8.7	2100
Nordhaus and Yang	1996	2.5°C	−2.1	2100
Plambeck and Hope	1996	2.5°C	−8.6	2200
Mendelsohn, Morrison, et al.	2000	2.5°C	−3.6	2100
Mendelsohn, Schlesinger, and Williams	2000	2.5°C	−0.5	2100
Nordhaus and Boyer	2000	2.5°C	−3.9	2100
Tol	2002a	1.0°C	−4.1	2050
Hope	2006	2.5°C	−2.6	2100
Baarsch et al.	2020	2.6°C to 8.5°C	−4.0 to −8.0	2050
Kompas et al.	2018	1.0°C	−2.2	2100
Kompas et al.	2018	2.0°C	−4.9	2100
Kompas et al.	2018	3.0°C	−8.1	2100
Kompas et al.	2018	4.0°C	−11.8	2100

Source: Author's compilation from the literature.

Even though the African region overall is on the losing side of climate change effects, within Africa the impact of climate change is not homogeneous. Figure 9 plots the estimated mean and median impact of climate change on GDP per capita by subregion in Africa over time under a 3°C global warming scenario. The projected impacts on GDP per capita depict regional specificity, except in northern and central Africa and southern Africa, where the impact pattern seems similar and modest. The worst-affected regions (the western African and eastern African regions) depict different patterns of impact. Whereas the severe reduction in GDP per capita is likely to kick in over the next two decades for the western African region, the eastern African region is likely to experience the worst economic loss sometime after four decades.

FIGURE 9. Regional heterogeneity in climate change impact at 3°C over time

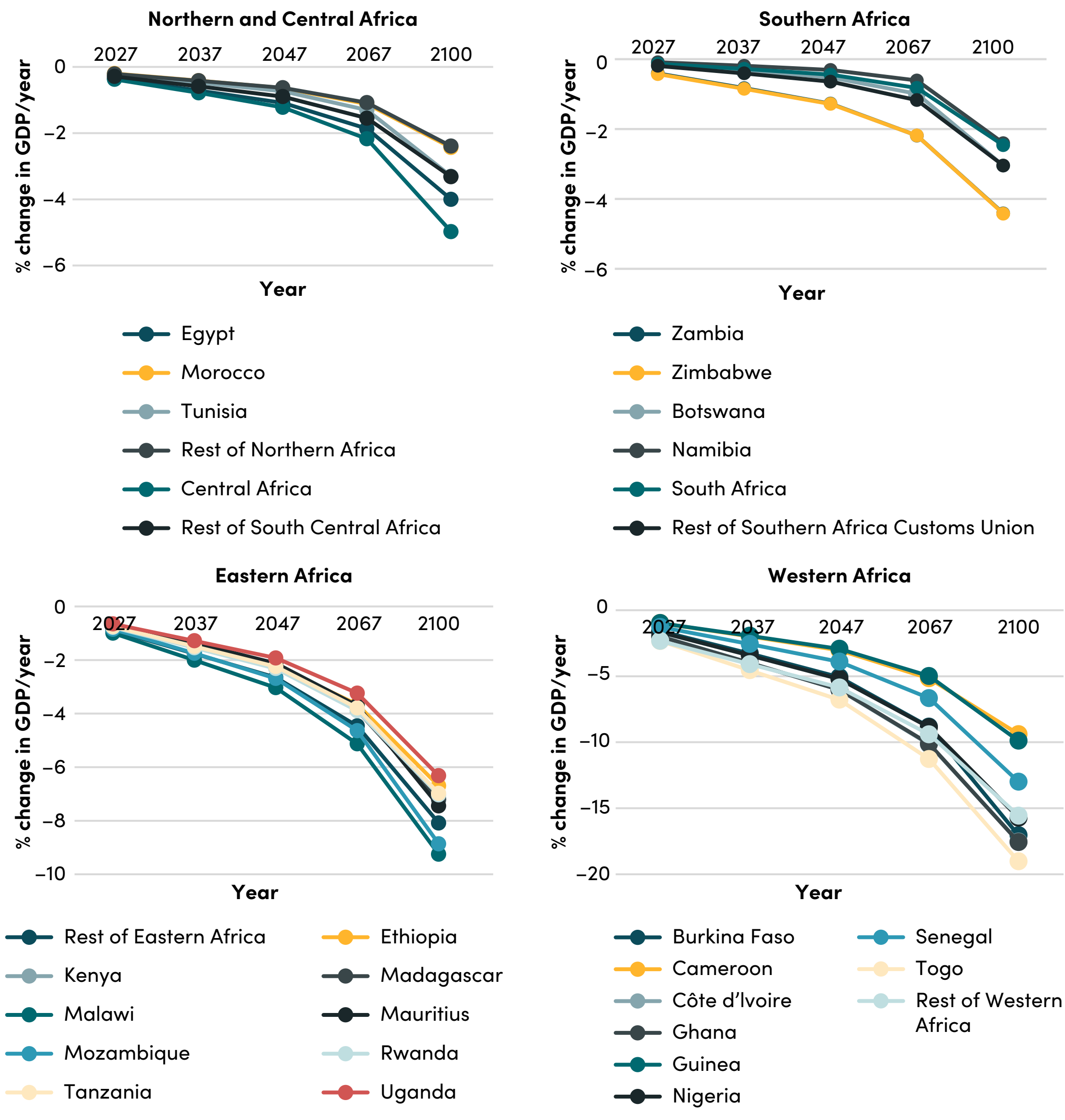


Source: Authors' construction using data from Kompas et al. (2018).
Note: EA = eastern Africa; NCA = northern and central Africa; SA = southern Africa; WA = western Africa.

Even within subregions, the impact is heterogeneous. Figure 10 plots the climate impact on output for various countries in Africa assuming 3°C warming. Clearly, even in the worst-affected subregions, such as western and eastern Africa, the risk of exposure to climate change differs by country. In the western African subregion, Togo, Ghana, Burkina Faso, Nigeria, and Côte d'Ivoire are expected to be the hardest-hit countries in the long term (i.e., by 2100). In eastern Africa, Malawi, Mauritius, Kenya, and Mozambique are likely to be the most affected by climate change in the long term. Again, as depicted in Figure 11, African countries differ in terms of the degree of exposure to varying levels of global warming.

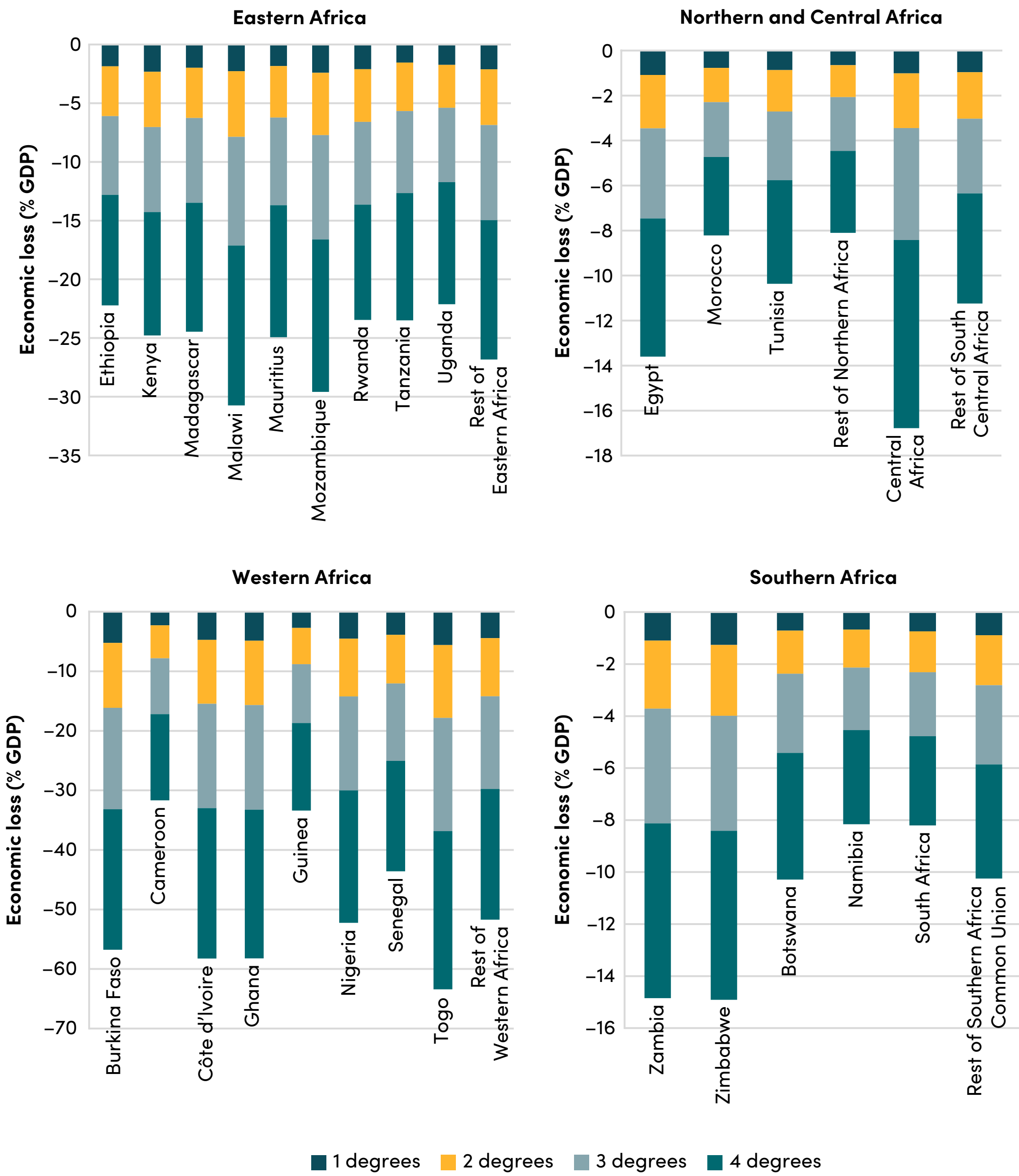
There are various channels through which the negative effects of climate change on economic growth could manifest. In the next subsection of the review, we discuss the implications of climate change effects on the agricultural sector, water resources, health, and energy security.

FIGURE 10. Country-level heterogeneity in climate change impact at 3°C over time



Source: Author's construction using data from Kompas et al. (2018).

FIGURE 11. Subregional climate change impact on GDP in Africa by varying temperatures



Source: Author's construction using data from Kompas et al.

3.2 Impact of climate change on agricultural productivity

Most developing economies depend heavily on the primary sector. Given that the primary sector also critically depends on temperature and precipitation, any abnormal and irregular changes in these climate indicators will affect the activities of the agricultural sector. Specifically, climate change is expected to impact farmland and labor productivity as well as food security for several decades, even if mitigation measures are implemented now (Valenzuela and Anderson, 2011). Climate change can reduce food production by (1) directly altering agroecological conditions; (2) indirectly affecting demand for agricultural products, income distribution, and economic growth; and (3) reducing the availability of suitable land for agriculture (Schmidhuber and Tubiello, 2007). However, some argue that the impact of climate change on farming in developing countries may lead to gains for farming households because the slump in agricultural output at a time of population growth will exert pressure on food prices to increase (Valenzuela and Anderson, 2011). This section reviews studies on the predicted future impact of climate change on food security and land use, with the aim of identifying the trends and patterns of climate change impact.

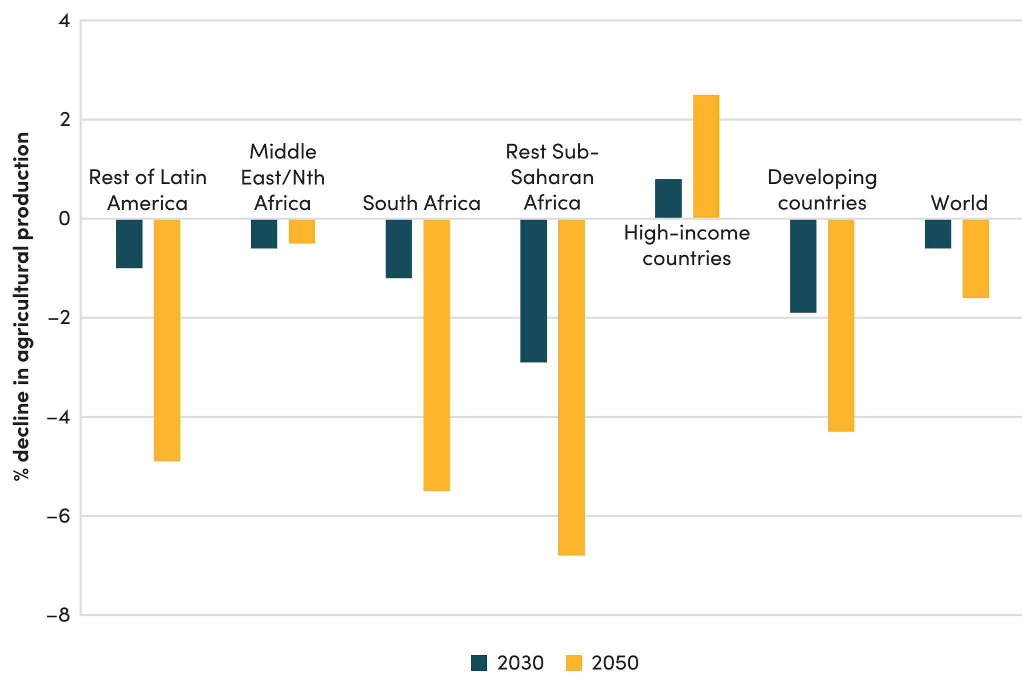
3.2.1 Food security

UN SDG targets 2.1 and 2.2 aim at ending hunger and ensuring access to safe, nutritious, and sufficient food for all people all year round, and eradicating malnutrition in all its forms. Prior to the COVID-19 pandemic, food security indexes had remained relatively unchanged since 2015. However, with the advent of the pandemic, food insecurity increased significantly. Globally, estimates show that approximately 2.3 billion people face moderate or severe food insecurity (FAO et al., 2022). The prevalence of undernourishment increased from 8 percent in 2019 to 9.8 percent in 2021 (FAO et al., 2022). Asia, Africa, Latin America, and the Caribbean were the most affected regions. In these regions, 425 million, 278 million, and 56.5 million people were undernourished in 2021, respectively (FAO et al., 2022). With climate change affecting the global food supply chain, more people might face extreme food insecurity. This section discusses the literature on developing economies, with some bias toward Africa, to determine whether there might be serious concerns about food security in the future due to climate change.

At the global level, studies agree that the impact of climate change on agricultural output is likely to be small, but significant heterogeneities exist across different locations. Fischer et al. (2005) assessed the impact of climate change on agricultural GDP to be moderate globally, varying from −1.5 percent to +2.6 percent from the baseline projection. In monetary terms, the negative impact of climate change translates to an agricultural GDP loss of US$2.9 trillion to US$3.6 trillion (1990 US dollars). The study further revealed that the negative impact of climate change on agricultural output will be felt the most strongly in developing countries. North America and the former Soviet Union will see agricultural GDP gains of 3.13 percent and 23 percent, respectively, while in Western Europe, agricultural GDP will fall by 6 to 18 percent. In most developing countries, climate change will reduce agricultural GDP. Experts predict that agricultural GDP in Asia will fall by 4 percent by 2080, while agricultural GDP in Africa will fall by 2–9 percent, compared to the baseline.

A simulation study by Valenzuela and Anderson (2011) using global-level data revealed that the response of yield to climate change shocks is expected to be negative in developing countries and overall, but positive in high-income countries. In developing countries, the researchers expect climate change to shrink agricultural output by 1.9 percent by 2030 and 4.3 percent by 2050, compared with a no-warming scenario (see Figure 12). For both 2030 and 2050, the relative decline in agricultural output is likely to be particularly steep in Africa. As shown in the figure, the decline in agricultural output in sub-Saharan Africa excluding South Africa is projected to be 2.9 percent in 2030 and 6.8 percent in 2050, compared with the 1 percent and 4.9 percent decreases in agricultural output in 2030 and 2050, respectively, for Latin America. These results indicate that the impact of climate change on agricultural output is likely to be moderate in the next decade, but beyond that the impact will be significant. Due to the slack in agricultural output, the simulation results reveal a change in agricultural prices in the opposite direction from the change in agricultural output. Consequently, agricultural value added (accounting for price changes) may show the opposite sign to the volume of farm output. However, for developing countries, the simulation results indicate that agricultural value added would rise, but only in a few countries.

FIGURE 12. Climate change impact on agricultural output



Source: Author's own construction.

These observations are reinforced in other studies such as Calzadilla et al. (2013), Gurgel et al. (2021), Molotoks et al. (2021), Wiebe et al. (2019), Li et al. (2022), and Schmidhuber and Tubiello (2007). Calzadilla et al. (2013) projected that global agricultural production will fall by 0.5 percent in the medium term and 2.5 percent in the long term, compared to the no-climate-change scenario, but there is evidence of regional differences. Countries in the Middle East, South Asia, and Africa are likely to be most affected. The authors found that in Africa, when they consider precipitation only, precipitation plus carbon dioxide fertilization, water only, and water plus land factors, total crop production decreases in both the pessimistic and optimistic scenarios. In addition, the authors note that rainfed crop production will suffer more than irrigated crop production. Although moderate precipitation could reduce the yield gap between rainfed and irrigated crop production in the 2020s, by 2050 rainfed crop production will decline due to heat stress.

The expected consequence of the decrease in agricultural production is a rise in world agricultural prices. The predicted increase in world food prices is much more substantial in 2050 than in 2020 under both the pessimistic and optimistic scenarios. Particularly for cereal grains, sugarcane, sugar beet, and wheat, world food prices are expected to rise between 39 and 43 percent, depending on the emissions scenario assumed by 2050.

Wiebe et al. (2019) combined socioeconomic models with climate change models and developed three case scenarios: an optimistic scenario (SSP1-RCP4.5), with slow growth in population, fast growth in income, and slow growth in greenhouse gas emissions; a pessimistic scenario (SPP3-RCP8.5), with fast population growth, slow growth in income, and fast growth in greenhouse gas emissions; and an intermediate case (SSP2-RCP6). Their study also projects that at the global scale, yields of major crops will decline by 5–7 percent relative to levels in 2050 in the absence of climate change under the SSP1-RCP4.5 and SSP3-RCP8.5 scenarios. In absolute terms, this represents a loss of about a tenth of the projected growth due to improved management practices and technology. The total global production and consumption of five food crops is projected to decline by 1 percent in 2050 relative to the levels expected in the absence of climate change. Higher-latitude areas are likely to experience less impact than lower-latitude areas. Due to the decline in output, prices are expected to increase by 10–15 percent, doubling the increases projected in the absence of climate change. The decline in agricultural yield projected by Wiebe et al. is smaller than that projected by Nelson et al. (2014), who predicted an 11 percent decline in yield and a 20 percent rise in prices for the SSP2-RCP8.5 case. The observed differences could be due to variations in the models. For example, Wiebe et al. attempted to introduce greater flexibility into the model in response to different climate change situations, such as less-extreme pathways, updates in the definition of the drivers of SSPs, and the inclusion of sugar as a crop. However, Wiebe et al. did not account for carbon dioxide fertilization and excluded other important climate change effects such as extreme temperature and precipitation, melting of glaciers, and rising sea levels.

Hertel et al. (2010) also estimated a much larger range of potential food price changes than those reported in recent studies. In the low-productivity scenario, prices for major staples are expected to rise by 10–60 percent by 2030. However, under the medium- to high-productivity scenario, prices for these major staples are projected to decline – substantially, in the case of the high-productivity scenario (decreasing by 5 to 20 percent by 2030).

Nelson et al. (2010) revealed that in the optimistic (high income growth and low population growth) and pessimistic (low income growth and high population growth) cases, climate change will reduce the daily caloric availability in developing and low-income countries, with the decline expected to be larger in low-income countries both in 2010 and in 2050. For some crops, yield growth might be higher in low-income countries than in middle-income countries, but this does not apply to the important irrigated crops.

Table 3 summarizes the predicted yield change between 2010 and 2050 due to climate change for different crops in different geographical locations. These values represent the average for the two scenarios with temperature increases of 1.4°C and 2.8°C. In developed economies, the predicted decline in maize, rice, and wheat yields is greater for rainfed than for irrigated crops. The reverse is true in developing economies and middle-income developing countries. The case for low-income countries is mixed; for some crops, such as maize and rice, irrigated crops will be harder hit by climate change than rainfed crops. However, with regard to, wheat crops in low-income countries, climate change will reduce the yield of rainfed wheat crops more than that of irrigated wheat crops. Nelson et al.'s simulation results highlight an important consideration: whether climate change will impact rainfed crops more than irrigated crops or not might depend on the geography being considered.

TABLE 3. Predicted yield change (%) between 2010 and 2050 due to climate change

Region	Maize		Rice		Wheat	
	Irrigated	Rainfed	Irrigated	Rainfed	Irrigated	Rainfed
Developed	−9.01	−17.14	−9.30	−12.96	−8.52	−6.47
Developing	−4.56	−2.16	−10.84	−0.47	−11.78	−7.27
Low-income	−3.20	−1.82	−9.42	+0.51	−11.33	−14.90
Middle-income developing	−4.62	+2.21	−11.14	−9.85	−11.81	−6.86
World	−5.74	−7.00	−10.80	−0.98	−11.57	−6.97

Source: Author's computation using the original figures presented by Nelson et al. (2010). These figures represent the average predicted effect for the two global warming scenarios (1.4°C and 2.8°C) for 2050.

Looking at individual crop prices, in a world of climate change with no mitigation, the price increase between 2010 and 2050 is 31.2 percent for rice in the optimistic case, compared to 58 percent for the baseline and 78 percent for the pessimistic case. In the case of maize, the price change between 2010 and 2050 is 87.3 percent in the optimistic case compared with 100.7 percent in the baseline scenario and 106.3 percent in the pessimistic case. In a world of mitigation, the price increases are lower compared with the situation of climate change with no mitigation.

Berhane (2018) reported that climate predictions suggest a substantial yield decrease in low-latitude areas. Li et al. (2022) simulated the future effect of climate change on global maize production under 1.5°C and 2°C global warming, compared with the baseline value of 0.6°C above the preindustrial level (the period of 1859–1900). Yield changes vary with warming level, time, and geographical location. Maize yield changes by −10.8 percent at 2°C and by +0.18 percent at 1.5°C. The distribution of the loss is concentrated in the middle- and lower-latitude areas of South America, in Asia, and in the middle latitudes of Africa and North America.

Specific region and country case studies also report negative impacts of climate change on specific crop yields – sometimes with much larger reductions in output compared with global-level studies. Khan et al. (2020) conducted a study on the economic effects of climate change–induced loss of agricultural production by 2050 in Pakistan. They project that climate change–induced wheat and rice crop loss will result in a US$19.5 billion decrease in Pakistan's real GDP compared to a no-climate-change scenario. This represents a 14.7 percent and 20.5 percent reduction in wheat and rice yield, respectively, by 2050.

Chalise et al. (2017) conducted a study on the general equilibrium of climate change–induced loss of agricultural productivity in Nepal. They reported that climate change has a significant negative impact on the entire Nepalese economy due to the induced loss of agricultural productivity. They note that rural households in Nepal, whose livelihoods primarily depend on subsistence farming, will face additional climate change–induced stresses due to significant already existing poverty and a weak social welfare system. Their simulation results show that the projected impact of climate change on agricultural productivity negatively affects real GDP, and real GDP is expected to decrease by 10.03 percent in the highest-impact scenario, 6.56 percent in the medium-impact scenario, and 2.49 percent in the lowest-impact scenario. This is largely due to the negative impact of climate change on agricultural output in Nepal. By 2050, climate change will reduce agricultural output from the baseline level by 6.7–7.6 percent. For rice, the yield will fall by 0.8–7.22 percent across scenarios. For wheat, the predicted decline is 1.28–5.45 percent. For cereal grains, the predicted decline in yield for the three scenarios is 2.43–8.43 percent.

Do Prado Tanure et al. (2020) conducted a study on the impacts of climate change on agricultural production, land use, and the economy of the Legal Amazon region between 2030 and 2049. They suggest that a climate-driven drop in economic indicators in the Legal Amazon will lead to a loss of real GDP on the order of 1.18 percent in 2049 due to a decrease in production and employment in the agricultural sector. Specifically, yields for crops such as rice, corn, soybean, and sugarcane are predicted to decline by 7.55 percent, 7.9 percent, 7.87 percent, and 11.34 percent, respectively, between 2030 and 2049 in Amazon Legal.

Srivastava et al. (2021) studied the impact of climate change on maize yield and yield attributes under different climate change scenarios in eastern India. They reported that the estimated change in yield was between –10.58 percent and –23.39 percent during the period 2021–2050, and between –15.20 percent and –26.83 percent during 2051–2080 for irrigated areas. However, for rainfed maize, the change in yield recorded due to climate change was less significant, ranging from –10.55 percent to +9.20 percent for the period 2021–2050, and from +4.31 percent to +10.63 percent during the period 2051–2080. These results indicate that the loss of grain yield is greater for the period 2051–2080 than for 2021–2050 under irrigated conditions, in comparison to the baseline yield, while under rainfed conditions, the grain yield increases in both the time periods 2021–2050 and 2051–2080. The impact of climate change is thus less significant under rainfed conditions than under irrigation conditions. The likelihood that irrigated rice yields will be impacted more by climate change than rainfed rice yields stems from the fact that rainfall in the future is predicted to be higher, which could make irrigated conditions counterproductive.

Jiang et al. (2019) examined future changes in rice yields in the Mekong River Delta in Vietnam due to climate change and found reverse results in that region. They report that rainfed crops generally produce less yield than irrigated crops. Simulation results predict a decline in rainfed rice yields of 35 percent in 2020–2029, 16 percent in 2030–2039, and 21 percent in 2040–2050, under the A2 climate change scenario (1.7°C to 2.2°C) during the winter period. These predicted declines are due to decreases in future rainfall. In contrast, irrigated rice yields in Hau Giang are likely to increase by approximately 11 percent in the 2020s, but in the 2030s and 2040s they are projected to decrease by approximately 0.5 percent and 23 percent, respectively. Meanwhile, during the summer season, crop simulations indicate that climate change is likely to reduce rainfed rice yields by approximately 49 percent from 2020 to 2029, by approximately 56 percent from 2030 to 2039, and by approximately 40 percent from 2040 to 2050. The seemingly inverted U-shaped effect of climate change is due to predicted higher rainfall in the 2040s than in the 2030s. Irrigated rice yields in Hau Giang are likely to decrease marginally, by approximately 5 percent, during the 2020s, but during the 2030s and 2040s they are projected to increase by approximately 2 percent and 5 percent, respectively, in the summer season.

Sinnarong et al. (2019) and Ansari et al. (2021) also found negative effects of climate change on rice production. Sinnarong et al. (2019) estimated that future climate change will lead to an overall decrease in mean rice production in Thailand of 9.37 percent in 2030 and 33.77 percent in 2090. Their study provides evidence of spatial variation. Climate change has the greatest effect in the north, where the projected decline in mean rice production ranges from 2.01 percent in 2030 to 11.61 percent in 2090. Similarly, Ansari et al. (2021) predicted that changing rainfall patterns, rising temperatures, and intensifying solar radiation under climate change may reduce rice yield in all three growing seasons in Indonesia. Under RCP8.5, the second dry season may see a decrease in rice yield of up to 12 percent in the 2050s, compared with the baseline of the no-climate-change scenario.

Other crops such as wheat, potato, and sugarcane are not exempt from the negative effects of climate change. Kumar et al. (2014) projected that climate change will reduce wheat yield in India by 6–23 percent by 2050 and by 15–25 percent by 2080, compared with a no-climate-change scenario. The negative impacts of climate change are projected to be less severe in low-emission scenarios than in high-emission scenarios. Differences in sowing times are one of the major reasons for the differences in predicted impacts on wheat yield in India. Late-sown areas are projected to suffer more than early-sown areas. Considerable spatial variation in the impacts is also projected. The warmer central and south-central regions of India may be more affected. Despite carbon dioxide fertilization benefits in the future, reduced wheat yield is projected in areas with mean seasonal maximum and minimum temperatures of more than 27°C and 13°C, respectively. In addition, projected yield reductions may be minimized to 9 percent in 2050 and to 13 percent in 2080 if adaptation measures are implemented, such as the use of efficient inputs and changes in sowing times.

Scott et al. (2019) researched future scenarios for potato production in India. The work used a multiperiod agricultural partial equilibrium economic model linked with a set of crop, climate, and water models to estimate potato supply in India for the period 2010–2030 according to three scenarios: an optimistic scenario (SSP1-RCP4.5, high economic growth and low population growth combined with less demanding climatic conditions), a middle-of-the-road pathway (SSP2-RCP6, moderate economic and population growth combined with more challenging climatic conditions), and a pessimistic scenario (SSP3-RCP8.5, slow economic growth and high population growth combined with more adverse climatic conditions). Their estimates of increases in potato production in India between 2010 and 2030 range from a high of 37.6 million metric tons under the optimistic scenario to a low of 23.9 million metric tons under the pessimistic scenario. These outcomes are derived from increases in average yields that range from 19.9 metric tons per hectare in 2010 to 27.1 metric tons per hectare in 2030 under the most favorable set of assumptions, or 23.5 metric tons per hectare under the more pessimistic set of assumptions, and corresponding annual compound growth rates for yields ranging from 1.48 percent to 0.8 percent per year.

Pipitpukdee et al. (2020) conducted a study on the impacts of climate change on sugarcane production in Thailand under climate scenarios RCP4.5 and RCP8.5. They reported that climate variables impacted the yield and harvested area of sugarcane. Increased population density reduced the harvested area in favor of nonagricultural use. Considering simultaneous changes in climate and the demand for land for nonagricultural development, the study revealed that future sugarcane yield, harvested area, and production are projected to decrease by 23.95–33.26 percent, 1.29–2.49 percent, and 24.94–34.93 percent, respectively, during 2046–2055, from the baseline (i.e., 1992–2016). Overall, the reduction in sugarcane production is more severe under adverse climatic conditions (RCP8.5) than under mild climatic conditions (RCP4.5). Sugarcane production is projected to experience the largest decrease in the eastern and lower sections of Thailand's central regions. The projected declines in production could adversely affect the well-being of one million sugarcane growers and the stability of sugar prices in the world market.

Schlenker and Lobell (2010) assessed the impact of climate change on agricultural products in Africa. They found that the impacts of climate change on maize, sorghum, and millet resulted in median production decreases of 22 percent, 17 percent, and 17 percent by mid-century, relative to the baseline scenario of no climate change. A more recent study by Emediegwu et al. (2022) simulated a much larger decline in millet yield under the RCP8.5 scenario for the period 2040–2069. The study projects a 48–55 percent reduction in millet yield compared with a no-climate-change scenario.

Thornton et al. (2010) conducted a study on the impact of climate change on agricultural systems and households in East Africa. Average production losses in the region due to climate change are estimated at 8 percent by 2050, compared to a no-climate-change scenario. However, the impact differs by country and agroecological zone. National maize production with climate change, relative to baseline, is projected to increase by 9.1 percent by 2030 and 9.1 percent by 2050 for Burundi; by 15.8 percent and 17.8 percent by 2030 and 2050, respectively, for Kenya; and by 10.8 percent and

14.9 percent for Rwanda. However, production for the same periods is projected to decrease by 3.1 percent and 8.1 percent for Tanzania and by 2.2 percent and 8.6 percent for Uganda. For beans, all countries except Uganda recorded positive changes in production in 2030. In addition, apart from Uganda and Tanzania, which are likely to record negative changes, the rest of the countries register positive changes in bean production. When the agroecological production system is considered, the effect of climate change on production of maize and beans is positive both in 2030 and in 2050 but relatively larger in the latter case for the temperate zone. However, for the humid production system, the effect of climate change is negative in 2030 and 2050, except for Rwanda in the case of maize production. For beans, the effect is largely positive in 2030 but becomes negative in 2050. These results indicate temporal and spatial variations in the impact of climate change on agricultural production, even within Africa.

Roudier et al. (2011) focused on future climate change effects on West African crop yields. They revealed that the impact of climate change is larger in northern West Africa (the Sudano-Sahelian countries of Niger, Mali, Burkina Faso, Senegal, and Gambia, with a median response of –18 percent) than in southern West Africa (the Guinean countries of Benin, Togo, Nigeria, Ghana, Liberia, Sierra Leone, Cameroon, Guinea, Guinea Bissau, and Côte d'Ivoire, with a median response of –13 percent), which is likely due to drier and warmer projected conditions in the northern part of West Africa. Moreover, the negative impacts on crop productivity increase in severity as warming intensifies.

Ben Mohammed et al. (2002) assessed the impact of current climate variability and future climate change on millet production in Niger. They found that by 2025, on average, the yield of millet will decrease by 13 percent due to climate change. Adejuwon (2006) examined the effects of climate change on food crops in Nigeria by analyzing both low- and high-latitude locations for the periods 2010–2039, 2040–2069, and 2070–2099. Under global warming of 4°C, the study found that maize and rice yields will decrease by 11 percent and 22 percent, respectively, compared with the baseline scenario of no climate change. Paeth et al. (2008) predicted the impact of climate change on different crops in Benin by 2025. While crops such as cotton, yam, and manioc showed some resilience to climate change, climate change significantly affected maize, rice, and sorghum. Yields for these crops are predicted to fall by 4 percent, 3.5 percent, and 2.5 percent, respectively. Tingem and Rivington (2008) assessed the impact of climate change on various crops in Cameroon assuming A2 (pessimistic, high) and B2 (optimistic, medium – low) climate scenarios for 2020 and 2080. They found that under different climate scenarios, different crops respond differently to climate change. Under the A2 scenario (excessive climate scenario – pessimistic scenario), for example, without adaptation, the simulation result showed that by 2080, the yield for maize will fall by –14.6 percent and for sorghum by 33.9– percent, compared with the baseline scenario of no climate change. For soybeans, it is expected that climate change will result in a 12.9 percent increase in yield. With adaptation, maize ad sorghum yield will increase under both climate scenarios.

In addition, Siddig et al. (2020) investigated the impact of climate change and agriculture in Sudan, looking at impact pathways beyond changes in mean rainfall and temperature. Yield changes by

2050 for rainfed maize, millet, sorghum, and sesame, due to drier conditions, are −59.5 percent, +13.9 percent, −14.3 percent, and −24.5 percent, respectively, compared to the no-climate-change condition.

Butt et al. (2005), in their study on the economic and food security implications of climate change in Mali, found that under climate change, crop yield changes will be in the range of −17 percent to +6 percent at the national level by 2030, compared with a baseline scenario. Simultaneously, forage yields will fall by 5–36 percent and livestock animal weights will be reduced by 14–16 percent. The resultant economic losses from these productivity declines range between US$70 and US$142 million, with producers gaining but consumers losing. However, the authors found that with adaptation intervention, the negative impact of climate change on these crops would be reduced. For instance, with adaptation, yields for maize, sorghum, and millet will decrease by only 8.6–10.3 percent, 4.3–7.7 percent, and 0.7–8.3 percent, respectively.

Fosu-Mensah et al. (2019) conducted a study on the impacts of climate change and climate variability on maize yield under rainfed conditions in the subhumid zone of Ghana. They reported a likely six-week shift in the planting dates of the rainy season from the current (1980–2000) third week of March to the second week of May for the simulated period. They further reported that climate change also resulted in a projected yield reduction of, on average, 19 percent, and 14 percent for the Obatanpa maize variety under the A1B (high economic and population growth; 1.6°C warming) and B1 (convergent economic growth with stable population growth; 1.3°C warming) scenarios, respectively, for maize-maize continuous cropping. Likewise, Dorke maize yield is expected to decrease by 20 percent and 18 percent under A1B and B1, respectively, with increased yield variability under both scenarios.

Similarly, Solomon et al. (2021), in their study on the impact of climate change on agricultural production in Ethiopia, predicted a significant decline in crop production in the next four decades, with the severity increasing over time. Production of teff, maize, and sorghum are expected to decline by 25.4 percent, 21.8 percent, and 25.2 percent, respectively, by 2050, compared with the base period. Climate change will also cause losses of 31.1 percent of agricultural GDP at factor cost by 2050. These estimates are for scenarios in which there is no adaptation. In other words, it is assumed that no adaptation could take place within the forecast period. Obviously, given that agriculture in Ethiopia is heavily weather dependent, climate change could have a significant impact on the agricultural contribution to GDP. However, given that adaptation has been gradually integrated into agriculture over time, the predicted effect is likely to suffer from upward bias.

The foregoing research indicates that climate change is likely to affect future agricultural yields in developing economies more than in high-income countries. Given that most developing economies depend significantly on the primary sector, climate change might significantly impact the incomes of those who work in that sector. Table 4 provides a summary of the predicted impact of climate change on major crop yields, with some bias toward Africa.

TABLE 4. Summary of studies on the impact of climate change on crop yield with reference to a no-climate-change scenario

Study Author	Country/Region	Crop (% Change in Yield)							Year	Degree of Warming (°C)
		Millet	Wheat	Rice	Sorghum	Corn/Maize	Soybean	Sugarcane		
Khan et al. (2020)	Pakistan		–14.70	–20.50					2050	3.30
Sinnarong et al. (2019)	Thailand			–9.37 to –33.77					2030 to 2090	3.50 to 12.55
Chalise et al. (2017)	Nepal		–1.28 to –5.45	–0.80 to –7.22		–2.43 to –8.43			2030 to 2050	1.60 to 2.90
do Prado Tannure et al. (2020)	Legal Amazon			–7.55		–7.90	–7.87	–11.34	2049	1.40
Pipitpukdee et al. (2020)	India							–23.95 to –33.26	2046 to 2050	4.50 to 8.50
Siddig et al. (2020)	Sudan				–14.30	–59.50			2050	3.64
Jiang et al. (2019)	Mekong River Delta			–35.00					2050	1.00
Thornton et al. (2010)	Tanzania					–3.10 to –8.10			2030 to 2050	
	Uganda					–2.20 to –8.60			2030 to 2050	
	Rwanda					+10.80 to +14.90			2030 to 2050	
	Kenya					+15.00 to +17.80			2030 to 2050	
	Burundi					+9.10			2030 to 2050	
Fosu-Mensah et al. (2019)	Ghana					–14.19			2050	
Solomon et al. (2021)	Ethiopia				–25.20	–21.80			2050	
Adejuwon (2006)	Nigeria	+4.10		–22.00	+2.90	–11.00			2035 to 2085	2.00 to 4.00
Ben Mohammed et al. (2002)	Niger	–13.00							2025	
Butt et al. (2005)	Mali	–6.30 to –11.50			–11.50 to –17.10	–11.20 to –13.50			2030	
Chipanshi et al. (2003)	Botswana				+10.00 to +31.00	+10.00 to +36.00				
Tingem and Rivington (2008)	Cameroon				–33.90 to –39.90	–8.20 to –14.60	+54.60 to +64.40		2080	2.50 to 3.50
Jones and Thornton (2003)	West Africa					–10.00			2055	
Paeth et al. (2004)	Benin			–2.50	–3.50	–4.00			2020 to 2025	
Schlenker and Lobell (2010)	Sub-Saharan Africa	–17.00			–17.00	–22.00			2046 to 2065	
Emediegwu et al. (2022)	Africa	+48.00 to +55.00							2040 to 2069	

Source: Author's own compilation using data from the literature.

The first impression from Table 4 is that the studies are quite diverse in scope. This makes it difficult to compare results across countries and regions. The diverse scope of these studies also means that we have still not been able to build sufficient evidence on the impact of climate change on certain crops across the globe and across regions. This lack creates a policy challenge, particularly at the global and regional levels.

Table 4 also reveals that most studies focus on maize, sorghum, rice, and millet, with few studies considering other crops. Generally, studies both in Asia and in Africa have reported negative impacts of climate change on rice yield, but the evidence is mixed for crops such as sorghum, maize, and millet. Comparatively, the negative impact of climate change on rice yield seems higher in areas such as Pakistan, Thailand, India, and Nigeria. For maize, the evidence in Table 4 points to a moderate negative impact of climate change on yield in Asia compared with that in Africa.

Table 4 also shows that different crops may exhibit different degrees of resilience to climate change depending on geography. For example, while studies report that maize seems resilient to climate change in areas such as Rwanda, Kenya, and Burundi, in other areas such as Sudan, Ghana, Nigeria, Mali, Cameroon, Botswana, and Benin the maize crop seems not as resilient to climate change. The sorghum crop exhibits a similar variation. While the crop is more resilient to climate change in Nigeria, it is more vulnerable to climate change in areas such as Sudan, Ethiopia, Mali, Cameroon, and Botswana. These results reveal that even under the most unfavorable climate change conditions, certain crops may still perform well in certain areas. Understanding spatial dynamics in terms of agroecological differences could prove useful in predicting climate change impacts and implementing adaptation mechanisms.

The temporal and spatial variation associated with the impact of climate change indicates that risk is probably heterogeneous across time, crops, irrigation statuses, and geography. Priority should be assigned to the highest-risk areas in each region. In Africa, these are areas in the west and east, according to the available evidence.

The scenarios discussed above primarily reflect no adaptation. Many studies reviewed did not integrate adaptation into their models, thereby making their estimates upward biased. The assumption of no adaptation over the next century is improbable. Realistically, the adverse effects of climate change will naturally induce behavioral changes. When adaptation mechanisms are integrated into climate change models, studies reveal that the negative effect of climate change on crop yield is reduced. However, the estimated negative yield impacts even with adaptation indicate that adaptation mechanisms alone may not be sufficient to address the negative yield impact of climate change.

3.2.2 Farmland

A related channel through which the threat of climate change can be seen in the agricultural sector is the effect on land use and value. Usable agricultural land is shrinking due to population growth and climate change, which may significantly constrain food production and consumption in the future. Pastor et al. (2019), in their study on the global nexus of food–trade–water sustaining environmental flows, reported that an increase in land use by 100 million hectares would be required to double food production by 2050 to meet projected food demand. The relevance of land use and value to the agricultural value chain and the world food system has motivated research on the nexus between climate change and land use and value. Generally, the body of evidence is biased toward developed economies where quality and reliable data exist (see Mendelsohn et al., 1994; Seo and Mendelsohn, 2008; Mishra et al., 2015; Abidoye, Kurukulasuriya, et al., 2017; Abidoye, Mendelsohn, et al., 2017; Hossain, Qian, et al., 2019; Hossain, Arshad, et al., 2019). The literature is still limited from a developing economy perspective. Nonetheless, there is some consensus on the negative impact of climate change on farmland value, although temporal and spatial variations are associated with the impact.

Seo and Mendelsohn (2008) assessed the impact of climate change on farmland value in Latin America using data from more than 2,500 farmers in seven countries (Argentina, Brazil, Chile, Columbia, Ecuador, Uruguay, and Venezuela). The study, which covered all crops grown by small- and large-scale farmers, indicates that summer warming reduces farmland values for both small and large farms. The regression results specifically show that with warming of 1°C, farmland value decreases by US$175 per hectare, on average. Small landholdings are more vulnerable to higher temperatures than larger farmlands. Land values decrease by US$111 per hectare on small farms and by US$78 per hectare on large farms. However, summer rains increase the value of farmlands, particularly for smallholder farmers. The simulation results project that by 2060 and 2100, farmland values will fall by 20 percent and 53 percent, respectively, under the severe Canadian Climate Centre scenario. Smallholder farmers are likely to lose between 36 and 61 percent of their land's value by 2100. This indicates that without intervention, the poor, who largely operate small-scale farms, would be hard hit by climate change.

Hossain et al. (2020) conducted a study on the impacts of climate change on farmland values in Bangladesh. They also reported that farmland values are sensitive to climate change. The estimated marginal impact results revealed that increases in temperature are associated with losses in smallholder farmland values, whereas precipitation levels in both seasons positively influenced farmland values. There is temporal and spatial variation in the impact of climate change on farmland value. Areas such as the Old Brahmaputra River, High Ganges River, Old Meghna Estuarine, and Young Meghna Estuarine floodplains are expected to be particularly hard hit by climate change. In terms of the temporal dynamics, the study revealed that the reduction in farmland value due to climate change is likely to be moderate from 2021 to 2060 (8–10 percent) but higher from 2061 to 2100 (18–24 percent).

In Africa, Berhane (2018) predicts that by 2080, the total arid and semiarid land area in Africa will increase by 5–8 percent. This indicates a rise in desertification due to climate change.

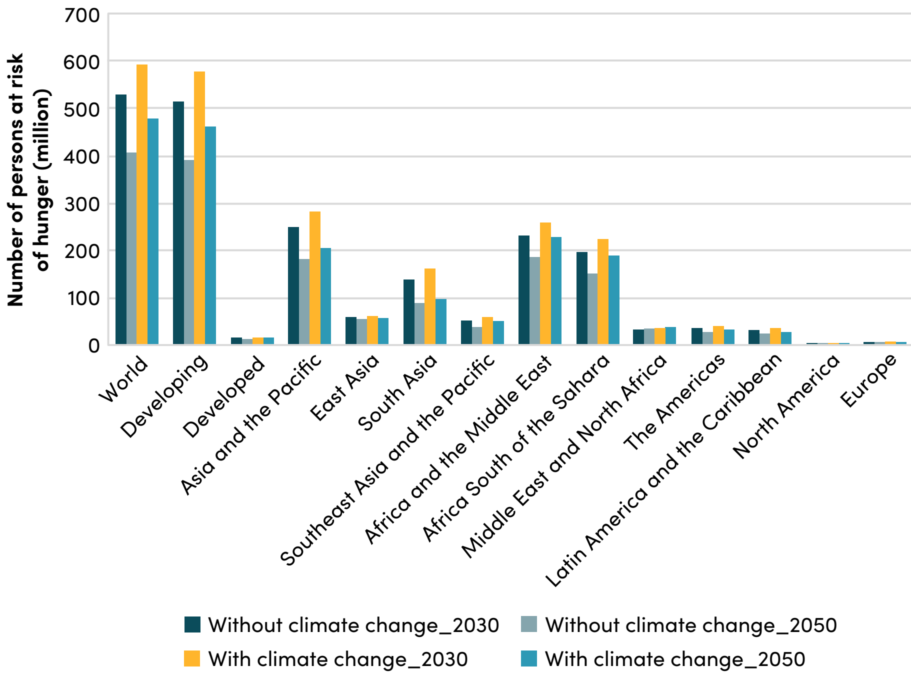
The literature on the impact of climate change on farmland value is limited for developing economies. The general evidence seems conclusive, although there are temporal and spatial variations. While rising temperatures reduce farmland value, increasing precipitation increases farmland value. Climate change is expected to have a greater effect on farmland values for small landholdings than for large landholdings. In terms of temporal dynamics, the impact on farmland values will be more substantial in the long term than in the medium term.

3.2.3 Hunger, undernourishment, and poverty

The immediate consequence of the negative impact of climate change on agricultural output is that many hundreds of millions of people, particularly in developing countries that rely on agriculture, risk facing extreme hunger, severe undernourishment, and income reductions. Rising agricultural prices due to climate-induced scarcity will also disproportionately affect the poor, who spend the bulk of their resources on food. Schmidhuber and Tubiello (2007) projected that by 2080, the number of undernourished people will increase by 5–26 percent relative to a no-climate-change scenario. The impact of climate change may drive between 5 million and 170 million additional people worldwide into severe or extreme hunger, considering the different scenarios.

Wiebe et al. (2019) predicted climate-induced implications for hunger. They found that under a no-climate-change scenario, most regions in the world will experience a more than 50 percent reduction in the number of people at risk of hunger by 2050, for a global total of around 406 million people, but the number will rise by 70 million people by 2050 under a climate change scenario. In sub-Saharan Africa, approximately two-thirds of the projected decline in the number of people at risk of hunger under the no-climate-change scenario will be lost, and more than 40 million people will be at risk of hunger by 2050 under a climate change scenario. Figure 13 summarizes the projected number of people at risk of hunger under no-climate-change and climate change scenarios in 2030 and 2050 across the different regions. The following can be deduced from the figure. First, in terms of spatial dynamics, more people will face hunger in developing economies than in developed economies. Among the developing economies, the Middle East and Africa south of the Sahara are expected to be the hardest hit subregions in the world in terms of the number of people likely to face hunger due to climate change. Second, the risk of extreme hunger due to climate change is, generally, more pressing in the medium term than in the long term. Comparing climate change versus no-climate-change scenarios, the risk of a higher number of people suffering from hunger is higher under the climate change scenario, implying that climate change might be pushing a significant number of people into extreme hunger.

FIGURE 13. Projected impact of climate change on the number of people at risk of hunger



Source: Author's construction using data taken from Wiebe et al. (2019).

Molotoks et al. (2021), in their assessment of the impact of climate change on the prevalence of undernourishment, examined increases relative to the baseline in the highest global impact (SSP3-RCP6) and lowest global impact (SSP1-RCP2.6) scenarios. Compared with the baseline, the prevalence of undernourishment due to climate change more than tripled in the highest global impact and lowest global impact scenarios, averaging 13 percent over the period. Regions such as Latin America, Africa, and parts of South Asia were identified as facing a high prevalence of undernourishment due to climate change. Within the lowest global impact scenario, more countries in Africa are likely to face high prevalence, but there is much variability in areas such as Latin America and South Asia. Southern Africa shows the most extreme difference between the lowest global impact and highest global impact scenarios; moving from "moderately low" impact in the former scenario to "very high" impact in the latter results in a more than 30 percent increase in the share of the region's population projected to be undernourished.

Nelson et al. (2010) also confirmed the negative impact of the climate-induced reduction in agricultural productivity on the number of malnourished children. While the number of malnourished children declines by 45 percent between 2020 and 2050 in developing countries under the optimistic scenario (high economic growth, low population growth, and less severe climate conditions), under the pessimistic scenario (low economic growth, high population growth, and more severe climate conditions), child malnourishment declines by only 2 percent during the same period. The researchers also found spatial variation in the impact of climate change on malnourishment in children. In the optimistic case, child malnourishment declines by 50 percent for middle-income developing countries and by 37 percent for low-income developing countries. However, in the pessimistic case, child malnourishment declines by just 10 percent in middle-income countries and increases by 18 percent in low-income countries. These results confirm the earlier narrative that children in poor developing economies are likely to suffer more severely from undernourishment due to climate change in the future. The authors estimate that productivity-enhancing programs such as improving irrigation efficiency could help reduce the number of malnourished children. Increasing irrigation efficiency by 15 percent is likely to reduce child malnourishment in middle-income countries by 0.3 percent and in low-income countries by 0.2 percent by 2050. These results affirm the importance of productivity-enhancing interventions as climate change adaptation measures.

Aside from the negative impact on hunger and malnourishment, there is potential for large income losses due to the negative effect of climate change on agricultural output. There is a large body of literature on the impact of climate change's effect on agricultural output on farm or crop revenues and hence poverty. Seo and Mendolshon (2003) assessed the implications of climate change for welfare in Latin America under three climate scenarios: severe, less severe, and moderate. They predict that Chilean farmers, on average, under the severe climate change scenario will lose 20 percent of their income by 2060 and 53 percent by 2100. Half of these estimated losses will be realized under the less severe climate change scenario and much less under the moderate climate change scenario. Their results reveal that both large and small farms will be very vulnerable to climate change, but the degree of vulnerability increases for smallholder farmers under high temperature/warming conditions, whereas the degree of vulnerability increases for large farms under increases in rainfall. Specifically, smallholder farmers will, under the severe climate change scenario, lose 24.1 percent of their net revenue by 2060 and 44.3 percent by 2100 compared to a no-climate-change scenario. The story is not much different for farmers with large landholdings, who are predicted to lose 18.2 percent and 66.3 percent of their net revenue by 2060 and 2100, respectively. A few factors could have introduced bias into these estimates, however. First, the adoption of a cross-sectional approach makes the model vulnerable to omitted variable bias. Second, the authors did not account for carbon dioxide fertilization, which is expected to increase productivity. Lastly, the cross-sectional approach means that the model is weak in handling temporal variation, which might include price changes and future technological advances.

Hertel et al. (2010) conducted a study on the poverty implications of climate-induced crop yield changes by 2030, accounting for the effects of carbon dioxide fertilization. The poverty impacts of these yield changes depend as much on where impoverished households earn their income as on the agricultural impacts themselves, with poverty rates in some nonagricultural household groups rising by 20–50 percent in parts of Africa and Asia under these changes, compared to the no-climate-change scenario, and falling by significant amounts for agriculture-specialized households elsewhere in Asia and Latin America. The potential for such large distributional effects within and across countries highlights the importance of looking beyond central case climate shocks and a simple focus on yields – or highly aggregated poverty impacts.

Solomon et al. (2021) also predict that climate change will affect the incomes and consumption of poor rural households more than urban nonfarming households. The incomes of poor rural people will decline by 20.4 percent by 2050, compared with the no-climate-change scenario, while nonpoor rural residents will see a 20.8 percent reduction. Incomes will fall by 20 percent by 2050 for poor urban residents and by 18.2 percent for nonpoor urban residents. Income from labor, land, and livestock in moisture-sufficient highland cereal-based areas will decline by 5.1 percent, 8.8 percent, and 15.2 percent, respectively, by 2050. The incomes of rural people in drought-prone areas will be severely affected by climate change. In drought-prone areas, climate change is expected to reduce the incomes of poor and nonpoor rural residents by 40.1 percent and 26.8 percent by 2050, respectively, compared to a 16.3 percent and 14.1 percent reduction for poor and nonpoor urban residents, respectively. The findings by Solomon et al. emphasize that even within the same country, with varying agricultural ecological zones, the impact of climate on household income is not likely to be homogenous. Studies such as Ochieng et al. (2016), Kabubo-Mariara and Karanja (2007), and Eid et al. (2007) reveal the negative effect of climate change on net revenue in Kenya and Egypt. Kabubo-Mariara and Karanja (2007) report that in Kenya, summer temperature has a U-shaped effect on crop revenue, whereas winter temperature has the inverse effect on crop revenue. Both summer and fall precipitation exert a direct positive effect on crop revenue. Their simulation results reveal a loss of between 28 percent and 69 percent in crop revenue in Kenya for all climate change scenarios.

Similarly, Ochieng et al. (2016) estimated the impact of climate change on crop revenue in Kenya. Their regression results showed that temperature has a negative effect on total crop revenue and maize revenue specifically, but a positive effect on tea revenue. In contrast, rainfall positively influences the revenues from all crops and from maize but not tea. Assuming a 1°C increase in temperature, crop revenue was predicted to fall by 14.2 percent by 2020. The projected loss in crop revenue increases to 14.8 percent in 2030 and 15.2 percent in 2040 as global warming increases to 2°C and 2.5°C, but the reverse is found for tea revenue, which increases by 2.3 percent in 2020, 2.4 percent in 2030, and 2.5 percent in 2040. In contrast, rainfall was projected to increase revenues for all crops by 0.8 percent in 2020, 0.9 percent in 2030, and 1 percent in 2040 but reduce tea revenue by 2.5 percent, 5.5 percent, and 8.8 percent for the same periods, respectively. These results confirm those of Eid et al. (2007) in Egypt, where they found that global warming of 1.5°C and 3.6°C reduces net revenue by US$116.67 and US$280.01 per hectare, respectively. Eid et al. also note that adaptation measures such as irrigation can reverse the negative impact of climate change; they estimate that irrigation would increase net revenues by US$39.26 and US$94.21 per hectare for 1.5°C and 3.6°C warming, respectively, compared with nonirrigated crops.

The foregoing discussion emphasizes the significant impact that climate change could have on hunger rates, undernourishment, and incomes. The research results are quite conclusive. However, we observed both spatial and temporal variations. For example, developing countries are predicted to have more people experiencing the risk of hunger, undernourishment, and lower incomes than developed countries. In terms of the temporal variation, the impact is more significant in the medium to long term than in the near future.

3.3 Impact of climate change on water resources

Water resources are used in various areas of the economy, society, and environment (Arnell, 1999). This means that the management of water resources is critical for achieving sustainable development. A significant proportion of the world's population suffers from severe water shortages. Currently, about 3.6 billion people in the world face inadequate access to water resources at least a month per year, and by 2050 this number is expected to rise to 5 billion people (WMO, 2022). The impact of climate change on hydrological cycles (IPCC, 1996) is likely to create a greater need for water as surface and groundwater levels diminish over time. Globally, hydrological cycles are shifting, creating drier days, severe floods, erratic rainfall patterns, and accelerated melting of glaciers (IPCC, 1996; WMO, 2022). More areas of the world recorded drier than normal conditions in 2021 compared with the average of the 30-year hydrological base period (WMO, 2022).

In the same year, 2021, areas such as India and China experienced severe floods, with numerous casualties. Tropical cyclones also affected areas such as Mozambique, Indonesia, and the Philippines (WMO, 2022). Areas such as Ethiopia, Kenya, and Somalia faced below-average rainfall, which caused severe drought in these economies in 2021. Also in Africa, rivers such as the Nile, Niger, and Congo experienced less than normal discharge in 2021 (WMO, 2022). In addition, terrestrial water storage was below normal in central parts of South America, North Africa, Patagonia, Madagascar, Central Asia, the Middle East, Pakistan, and North India and above normal in areas such as the central part of Africa, the northern part of South America, and the northern part of China (WMO, 2022).

This section reviews the future trends of climate change's impact on water resources from a developing country perspective, with some bias toward Africa.

Arnell (1999) analyzed the expected impact of global warming on global water resources. The findings suggest that average runoff is likely to increase in high latitudes in equatorial Africa, Asia, and Southeast Asia but is expected to decline in mid-latitudes and most subtropical regions. Increasing temperature leads to a general reduction in the proportion of precipitation falling as snow. This is likely to lead to a subsequent reduction in the duration of snowfall in many areas of the world. Therefore, stream flows, including their timing, in such regions would be negatively affected. The study estimates that the number of people suffering from water stress is likely to increase by 53 million people by 2025 under the climate change scenario of the Hadley Centre Coupled Model version 2 (HadCM2), relative to the no-climate-change scenario. Although this number is expected to fall by 2050 under the HadCM2 climate scenario, it would rise to 56 million people under the updated HadCM3 climate scenario. The problem of water stress will be exacerbated in areas such as the Middle East, the Mediterranean, parts of Europe, and southern Africa. The spatial and temporal variations in the impact of climate change on water resources are also highlighted in regional and country-specific case studies.

Studies in Asia, the Middle East, and South America also point to the negative effect of climate change on water resources (see, for example, Hashemi et al., 2015; de Moura et al., 2020; Mandal et al., 2021). Hashemi et al. (2015) conducted a study to assess the impacts of climate change on groundwater recharge and adaptation in arid areas of Iran. They reported that groundwater recharge modeling showed no significant difference between present and future recharge in all scenarios. De Moura et al. (2020) conducted a study on the hydrological impacts of climate change in a well-preserved upland watershed in Brazil. They reported that a well-preserved upland watershed in a subtropical region might be capable of maintaining water availability at a level that is sufficient for human activities in the future, even with the reduction of minimum permit discharge, which is supported by the increase of maximum and medium monthly discharges and a stable flow-duration curve. They further noted that the flow-duration curves in the future will be more affected under the RCP8.5 scenario than under the RCP4.5 scenario, and the variations are very time-dependent. This indicates that severe climate change is expected to affect the future flow of water resources in Brazil, which could push more people into water stress.

Mandal et al. (2021) conducted a study assessing climate change and its impact on the hydrological regimes and biomass yield of a tropical river basin in India. They reported that a 14–36 percent increase in precipitation increases the runoff by 39.7–104.1 percent. Compared with 1950–2000 period a range of 100 percent and 200 percent in monsoon runoff is expected during 2030 and 2080, respectively. Projections of expected runoff volumes in the medium and long term reflect a higher degree of uncertainty. There is evidence of a significant rise in monsoon season runoff for the intra-RCP scenario only during 2070 and 2080. Potential evapotranspiration and actual evapotranspiration are predicted to increase by 2.2–12.7 percent and 1.0–9.0 percent, respectively, compared to a no-climate-change scenario, during the monsoon. The rise in precipitation due to climate change in monsoon areas suggests a rising risk of flooding as well as changes in the quantum of other hydrological fluxes. Based on the simulation output, the climate-driven increase in the volume of water in the basin is expected to cause a 2–3 percent decrease in the output of biomass.

Kundu et al. (2017) and Mishra and Lilhare (2016) confirm the rise in precipitation during the monsoon in India. Under the RCP 4.5 (8.5) scenario, Kundu et al. (2017) predicted a 17–26 percent rise in monsoon season precipitation, whereas Mishra and Lilhare (2016) predicted an increase of 50 percent in monsoon season precipitation across the rivers of India, except for the Ganga and Indus basins compared to no warming scenario. Sinha et al. (2020) assessed the impacts of climate change on surface runoff in a humid tropical river basin in the Western Ghats in India, assuming land use in 2000 to be constant. They projected that for the climate change scenarios assessed, mean annual surface runoff in the near (2011–2040), medium (2041–2070), and long term (2071–2099) would decrease. However, the decline is expected to be more negative in the near term than in the medium and long term under both RCP4.5 and RCP8.5. The decline in surface runoff is due to a predicted decline in rainfall of 10 percent, 4.14 percent, and 4.98 percent under the RCP4.5 and 11 percent, 4.6 percent, and 5.5 percent under the RCP8.5 scenarios, respectively for the three periods compared with the baseline period (1981–2010). The combined effects of changes in land use and climate showed that surface runoff will increase between January and May but decline from June to December, which may reflect the shift in rainfall from monsoon months to non-monsoon months. The decline in surface runoff from June to December indicates that during these months, irrigation schemes may suffer due to insufficient water storage. However, the increase in surface runoff during the winter and summer signals high flood risk.

Similarly, Kaini et al. (2022) studied the impacts of climate change on irrigation water demand, grain yield, and biomass yield of winter wheat in Nepal. They reported that farmers applied only 25 percent of the irrigation water required to achieve the maximum potential grain yield. Irrigation water demand is likely to increase under the RCP4.5 scenario (by 3 percent) but likely to decrease under RCP8.5 (by 8 percent) due to truncated crop duration and lower-maturity biomass by the end of the 21st century. In China, Xiong et al. (2010) simulated the effect of climate change on future water availability and found limited impact. Water availability for agricultural purposes declines in southern China but remains stable in northern China. The combined effects of climate change and socioeconomic development produce a reduction in future irrigated areas. Generally, the agriculture sector is likely to face severe water shortages due to competition for water for nonagriculture purposes and the effects of climate change.

The negative impacts of climate change on water resources have also been highlighted in Africa. Coulibaly et al. (2018) assessed the impact of climate change on water resource availability in a transboundary basin in West Africa. For the RCP4.5 scenario, their model predicts an overall decline in monthly precipitation compared to the baseline until 2070 and then a slight recovery in 2090. The RCP8.5 scenario predicts a shortened rainfall pattern and a lengthened dry season. In terms of annual rainfall, their model predicts that for both scenarios, annual rainfall will decline, with the worst case occurring under the RCP8.5 scenario. This indicates that climate change is likely to create a serious water shortage in West Africa. This result somewhat corroborates the findings of op de Hipt et al. (2018). The authors found that in West Africa under the RCP4.5 scenario, climate change will increase precipitation by 50 percent. However, under the RCP8.5 scenario, climate change will decrease precipitation by 10.9 percent. In terms of the impact of climate change on river discharge, Coulibaly et al. (2018) showed a negative impact until 2100 for both scenarios, compared to the baseline (1961–1980). For the RCP 4.5 scenario, the observed values vary from −1.2 percent in 2030 to −2.3 percent in 2070 and −2.1 percent in 2090. Under the RCP8.5 scenario, the researchers saw changes in river discharge varying from +4.2 percent to −7.9 percent in 2030 and 2090, respectively. This confirms the results of Andersson et al. (2006) in a study assessing the climate change implications for water flow along the Okavango River in southern Africa. The annual water flows for 2050–2080 and 2070–2099 show a decline of 14–20 percent and 17–26 percent, respectively, for all climate change scenarios. The authors found that the simulated impact of climate change on monthly water flow was proportionally higher than the impact on annual mean water flow.

Soro et al. (2017) assessed the impact of climate change on water resources in the Bandama basin in Côte d'Ivoire. The monthly rainfall may decrease from December to April. During this period, it is projected to decrease by 3–42 percent at all horizons (2006–2035, 2041–2060, and 2066–2085) under RCP4.5 and by 5–47 percent under RCP8.5. These variations suggest a reduction in surface and groundwater resources.

In addition, Ogallo et al. (2018) conducted a study on climate change projections and the associated potential impacts for Somalia. They reported a trend of decreasing rainfall leading up to 2030, followed by an increase in rainfall by 2050 and 2070.

Hamududu and Ngoma (2020) conducted a study on the impacts of climate change on water resource availability in Zambia. They reported that the temperature is projected to increase by 1.9°C and 2.3°C by 2050 and 2100, respectively, in Zambia. Rainfall is projected to decrease by approximately 3 percent by mid-century but only marginally, by approximately 0.6 percent, by the end of the century across the country. These changes in rainfall and temperature will decrease water availability by 13 percent by 2100 at the national level. At the river basin level, the northern basins are projected to remain the same or experience slight gains in water resources compared with those in the southern and western parts of Zambia, where reductions of up to 9 percent are projected. In particular, the Zambezi, Kafue, and Luangwa River basins are projected to have fewer water resources due to reduced rainfall and higher temperatures.

Boojhawon and Surroop (2021) conducted a study on the impact of climate change on the vulnerability of freshwater resources in Mauritius. They reported that for the period 2020–2050 under a business-as-usual scenario, the freshwater sector remained in a state of moderate vulnerability. Under the effects of climate change, this shifted to high vulnerability. The findings indicate that the country is likely to enter water scarcity (water availability of less than 1,000 cubic meters per capita) by 2030 and face overexploitation of water resources (a water exploitation rate greater than 100 percent) by 2040.

Other studies such as Githui et al. (2009) and Balcha et al. (2023) downplay the effect of climate change on rainfall patterns. Githui et al. (2009) examined the future implications of climate change on the Nzoia catchment in the Lake Victoria basin and how it might influence future stream flow in Kenya. Using the soil and water assessment models, they found increased amounts of rainfall but with monthly variation. Generally, rainfall is predicted to be higher in the 2050s than in the 2020s. In terms of the impact of climate change, the study found that a change in annual rainfall between 2.4 and 23.2 percent will trigger a change in stream flow of 6 to 115 percent. Holding other factors constant, a significant increase in stream flow is expected due to the rise in rainfall amounts in the future. Regarding the temperature and stream flow relationship, the study found that stream flow is not very sensitive to changes in temperature.

Balcha et al. (2023) conducted a study assessing the future impact of climate change on water balance components in the Central Rift Valley lakes basin in Ethiopia. They reported that future annual and seasonal rainfall will show increasing and decreasing trends, but they are statistically insignificant. Furthermore, future temperatures in the subbasins show a significant increase. For the applied scenarios, an increasing and decreasing trend of future rainfall and increased temperatures would decrease the water yield by 4.9–15.3 percent in the Katar subbasin and 6.7–7.4 percent in the Meki subbasin. Furthermore, annual water yields will increase in the range of 0.38–57.1 percent and 6.57–49.9 percent for the Katar and Meki subbasins, respectively. The researchers further noted that rainfall and temperatures in the study region are anticipated to increase by 2040 and 2070 under both the RCP4.5 and RCP8.5 climate scenarios.

The above research indicates that the impact of climate change on water resources is quite complex, ambiguous, and sometimes insignificant. In Asia, particularly in India, climate change is likely to lead to rising precipitation levels, which could increase the flood risk in the area. In addition, climate change is likely to reduce surface runoff, thereby posing a serious threat to irrigation schemes in India in the future. In China and Nepal, climate change is likely to affect future irrigated areas. The risks of flooding, reduced surface runoff, and reduced irrigated areas worsen under the very severe climate change scenario.

In Africa, the results look complex. Climate change is expected to reduce rainfall levels, surface runoff, and groundwater. Under less severe climate change scenarios, these impacts are quite mixed, as climate change is found to have both positive and negative impacts on precipitation. However, for the very severe climate change case, there is a unanimous conclusion that climate change might significantly reduce water resources in Africa. Nonetheless, there are concerns that African countries may experience an acute shortage of water resources even in less severe scenarios if appropriate water adaptation efforts are not implemented.

3.4 Impact of climate change on health

Climate change is known to be linked to multiple health issues, including respiratory diseases, heart disease and stroke, water- and food-related illnesses, poor mental health, and pest-related diseases. Climate health damages are projected to be between US$2 billion and US$4 billion globally by 2030. Between 2030 and 2050, approximately 250,000 people are expected to die from climate change–related health issues such as malnutrition, malaria, heat stress, and diarrhea (WHO, 2021). Developing countries with weak health systems and infrastructure will suffer the most from the health effects of climate change. Studies on climate change effects have looked at the future health implications of climate change with varied outcomes in terms of the degree of impact.

Notwithstanding the varying degrees of impact, there is some collective agreement within the literature on the possible negative effects that climate change could have on future health outcomes.

Li et al. (2018) conducted a study that sought to forecast future climate change impacts on heat-related mortality in large urban areas in China. They projected that for the 20-year period of 2041–2060, relative to 1970–2000, the incidence of excess heat-related deaths annually in the 51 cities studied will be approximately 37,800, 31,700, and 25,800 under the RCP8.5, RCP4.5, and RCP2.6 scenarios, respectively, for period 2041–2060. Slowing climate change by achieving the low-emission scenario, RCP2.6, relative to RCP8.5, was estimated to avoid 12,900 the number of deaths per year in the 51 cities will decrease by 12,900 in 2050s and by 35,100 in 2070s. The highest mortality risk is concentrated in cities located in the northern, eastern, and central regions of China.

Aboubakri et al. (2020) conducted a study that sought to project the mortality attributed to heat and cold and the impact of climate change in Kerman, a dry region of Iran. They reported the effect of climate change on mortality while considering adaptation. The models showed that the mean temperature will rise by 1°C by 2050 in all scenarios in Kerman. Correspondingly, heat-related mortality will rise in the future, whereas cold-related mortality might slightly decrease. There was significant uncertainty around cold-related deaths.

Chang et al. (2022) conducted a study on the impacts of climate change on health and labor force participation in Taiwan. They projected that a 1°C increase in average summer and winter temperature, and variation in temperature are associated with 2.9 percent, 1.3 percent, and 14.3 percent rise in the number of cardiovascular disease (CVD) deaths, respectively. The study predicts an additional 4,200–4,500 deaths from CVD (including 900–1,000 deaths among the labor force) per annum from 2021 to 2040, which is likely to rise to 5,600–6,300 CVD deaths. These findings suggest an increase in both the mortality and morbidity of CVD due to climate change. Consequently, on the expenditure side, increasing the average summer and winter temperatures by 1°C could be associated with 1.37 percent and 0.47 percent increases in CVD-related health expenditures, respectively. In contrast, raising annual precipitation by 1 percent is associated with a 0.08 percent decrease in CVD-related health expenditures.

Climate change is also expected to increase disease incidence in the future. Ermert et al. (2012) studied the impact of regional climate change on malaria risk due to radiative forcing and land-use changes in tropical Africa. They reported that the likelihood of malaria epidemics is projected to increase in the southern part of the Sahel compared with a no-warming scenario. In most East African countries, the intensity of malaria transmission is expected to increase. Projections indicate that malaria will become endemic in highland areas that were formerly unsuitable for transmission, whereas in the lower-altitude regions of the East African highlands, epidemic risk will decrease. In addition, climate changes driven by greenhouse gases and land-use changes will significantly affect the spread of malaria in tropical Africa well before 2050. The geographic distribution of areas where malaria is endemic may be significantly altered in the coming decades.

Shiravand et al. (2019) conducted a study on the effects of climate change on the potential distribution of the main vector and reservoir host of zoonotic cutaneous leishmaniasis in Yadz Province in central Iran. They projected that with both scenarios (RCP 4.5 and RCP 8.5) in 2030 and 2050, the mean temperature of the wettest quarter and the annual temperature range had the greatest effect on the model for the vector and reservoir hosts, respectively. There are spatial variations in the impact, however. While it is predicted that the presence of the vector will increase in the western part, the reservoir will increase in the northern and central parts of the province. Iwamura et al. (2020) conducted a study on the accelerating invasion potential of the disease vector *Aedes aegypti*, the yellow fever mosquito, under climate change. They reported that from 1950 to 2000, the world became approximately 1.5 percent more suitable per decade for the development of *Aedes aegypti*, and this trend is predicted to accelerate to 3.2–4.4 percent per decade by 2050. Invasion fronts in North America and China are projected to accelerate from 2 to 6 kilometers per year by 2050. An increase in peak life cycle completion combined with extended periods suitable for mosquito development was simulated to accelerate the vector's global invasion potential.

These studies reveal the negative impact of climate change on health, with spatial and temporal variations. As indicated, the effects of climate change on health are likely to be larger in the long term than in the short term. In addition, countries with weak health systems are likely to suffer more from the impact of climate change on health.

Due to the close connection between health and productivity, the negative effects of climate change on health could have negative implications for the growth of economies, particularly those in developing countries. Without climate mitigation intervention, the future effects of climate change could erode any positive gains achieved in health and hence derail efforts targeted at achieving sustainable development. Limiting global warming to within the 1.5°C limit could help protect millions of people from disease and death.

Transitioning to low-carbon technologies to reduce global warming also has positive impacts on health, thanks to these technologies' lower emissions of local pollutants. For example, West et al. (2013) studied the co-benefits of mitigating global greenhouse gas emissions for future air quality and human health. They reported that relative to a reference scenario, they found that mitigating global greenhouse gas could prevent 0.5 ±0.2 million, 1.3 ±0.5 million, and 2.2 ±0.8 million premature deaths in 2030, 2050, and 2100, respectively. The estimated global average marginal co-benefits of avoided mortality are US$50–380 per tonne of carbon dioxide. This is higher than the marginal abatement costs in 2030 and 2050 but within the low range of costs in 2100. It is estimated that East Asian co-benefits could be 10–70 times larger than the marginal cost in 2030.

Cai et al. (2018) conducted a *Lancet* Countdown study on the fine particulate matter ($PM_{2.5}$) pollution-related health impacts of China's projected carbon dioxide mitigation in the electric power generation sector under the Paris Agreement. The results showed that due to the more carbon-intensive nature of the energy sector, northwest China stands the risk of experiencing high implementation costs and premature death than the business as usual. By 2030, the air quality in northwest China (particularly in Gansu, Shaanxi, and Xinjiang provinces) will become worse and this is expected to cause more than 10,000 premature deaths in these areas, but this is expected to fall by 2050.

Dimitrova et al. (2022) conducted a study projecting the impact of air pollution on child stunting in India, examining synergies and trade-offs between climate change mitigation, ambient air quality control, and clean cooking access. They reported that reductions in the ambient air pollution under the 2°C Paris Agreement target positively influences the growth of children but climate change is likely to offset this positive effect through reduced access to clean cooking. Controlling ambient air pollution and subsidizing access to clean cooking could create a net benefit of 2.8–6.5 million prevented cases of child stunting between 2020 and 2050 compared with the business-as-usual scenario, with the greatest benefit falling on the most disadvantaged children and geographic regions.

3.5 Impact of climate change on energy security

UN SDG 7 aims to "ensure access to affordable, reliable, sustainable, and modern energy for all" by 2030. This goal was established to help address the energy poverty problem, which is considerable among the developing countries of the world. While some gains have been made, climate change could erode the initial advances, as it affects both energy demand and supply (IPCC, 2014). The energy system is vulnerable to a variety of climate change impacts, such as hurricanes, heat waves, wildfires, extreme weather, rising temperatures, and heavy rainfall (Zamuda et al., 2018). However, as these climate change events vary by location, the impact of climate change on the energy system is context dependent. Because most developing countries already face the challenge of poor and weak energy infrastructure, their energy systems are expected to be more vulnerable to climate change events than those of developed economies. Yalew et al. (2020) analyzed more than 200 studies that estimated the future impacts of climate change on the energy systems of global and regional economies. These studies predict a reduction in hydropower and thermal energy capacity, a rise in cooling demand, and a decrease in heating demand. At the regional level, the results look mixed and inconclusive, but the greatest impact of climate change on the energy system is likely to occur in Latin America and South Asia. In a similar literature review of climate change's impact on the energy supply, Cronin et al. (2018) note that while there is some consensus regarding the expected impact of climate change on some energy sources, such as wind, solar, and thermal, the impact projections vary for hydropower and bioenergy sources.

Some studies have reported the impact of climate change on energy demand and supply in a developing country context. Mei et al. (2020) conducted a study analyzing the impact of climate change on the energy–economy–carbon nexus in China. They projected that the national electricity demand would grow by around 58.6 percent in the next 30 years under climate change, compared with the no-climate-change scenario. The growth in energy demand associated with climate change was confirmed in a review study by Tahir and Al-Ghamdi (2023), who concluded that climate change increases energy requirements in the built environment. This was also confirmed by Campagna and Fioriti (2022) and Li et al. (2012). Li et al., however, note that the greatest impact occurs in the summer and warmer winter periods.

In the case of the power generation potential of solar photovoltaics (PV), Dutta et al. (2022) quantified the change in global solar PV power generation potential under climate change as ranging from −10 percent to +10 percent, depending on the SSP scenario. They noted that the increase in cloud coverage will reduce solar radiation and hence the power generation potential in Asia. Niu et al. (2023) confirmed this in China, when they assessed the power generation potential of solar PV under climate change scenarios. They noted that if global warming is limited to 1.5°C by 2100, solar PV power generation potential will rise by 1.36–5.90 Wm^{-2}. However, failure to achieve this global warming target will reduce the power generation potential of solar PV. Under SSP5-RCP8.5, the authors predicted that solar PV power generation potential will decrease from 192.71 Wm^{-2} to 189.96 Wm^{-2} in 2023–2100. Among the factors contributing to the reduced power generation potential for Solar PV, they note that solar radiation alone will be responsible for more than 50 percent, whereas aerosols and cloud cover would be responsible for about 20 percent.

In the case of wind power generation potential, Zhou et al. (2022) projected that under the SSP5-RCP8.5 climate scenario, average wind speed will fall by 40 percent, which would reduce wind power generation, particularly in northern China. Meanwhile, in the south of China, the authors found the potential of wind power generation to increase due to a predicted 2 percent increase in wind speed.

In Africa, studies have also confirmed the potential negative effects of climate change on power generation. Agbor et al. (2023) examined the impact of climate change on solar radiation and the power generation potential of solar PV in West Africa. Generally, they found that climate change might reduce solar radiation and hence reduce the power generation of solar PV in the future under the moderate and worst-case scenarios in 2015–2050 and 2051–2100. However, they noted that the decline depends on the type of solar PV technology adopted. Polycrystalline silicon technology seems to exhibit greater generation potential under both the moderate and best-case scenarios. Under the worst-case scenario, amorphous silicon technology produces a less than 1 percent increase in solar PV output, whereas the remaining technology (i.e., mono-crystalline, poly-crystalline, HIT hybrid silicon, cadmium telluride thin film, and indium gallium diselenide thin film) exhibits a less than 1 percent decline in solar PV output. Other regional studies on solar PV potential generally predict decreases of 10 percent in solar generation by the end of the century (Panagea et al., 2014; Gaetani et al., 2014; Crook et al., 2011).

Regarding the global impact of climate change on hydropower potential, the research results are not conclusive. While some studies predict minimal impacts (Hamududu and Killingtveit, 2012; Turner et al., 2017), others suggest a 6.5 percent decline under RCP8.5 by 2080 (van Vliet, van Beek, et al., 2016; van Vliet, Wiberg, et al., 2016). Bombelli et al. (2021) revealed that variability in cloud coverage, temperature, and precipitation could negatively impact the power generation potential of some hydropower sites in East Africa. Mirani et al. (2022) conducted a study on the evaluation of hydropower generation and reservoir operation under climate change in the Kesem Reservoir in Ethiopia. They reported that future climate scenarios predicted increasing and decreasing trends in temperature and precipitation, respectively. Under the RCP4.5 climate scenario, average energy generation is likely to decrease by 0.64 percent and 0.82 percent in the short term (2021–2050) and the long term (2051–2080), respectively. In the case of the RCP8.5 climate scenario, average energy generation will decrease by 1.06 percent and 1.35 percent in the short and long term, respectively. Comparatively, the reduction in energy generation was higher in the RCP8.5 scenario than in the RCP4.5 scenario. This indicates that there will be high energy fluctuations and a decreasing trend in future energy generation if global warming is not contained. In addition, the hydropower potential of the Zambezi River basin in Africa is predicted to decrease by 10 percent by 2030 and 35 percent by 2050 due to climate change (IPCC, 2014).

Fant et al. (2016) predict that climate change will have no significant impact on hydropower resources in southern Africa. The lack of consensus on the impact of climate change on hydropower generation potential is also highlighted in other local-level studies. For example, while van Vliet, van Beek, et al. (2016) project a 5.2 percent increase in hydropower potential in high-latitude areas, which is also confirmed by van Vliet, Wiberg, et al. (2016), Hamududu and Killingtveit (2012) project a plus or minus 1 percent change in hydropower generation potential under different climate scenarios.

The following can be deduced from the above discussion on the impact of climate change on energy systems. Climate change may be a significant threat to energy security in developing countries, particularly when we consider the implications of climate change for the demand side of the energy sector. However, on the supply side, the situation is less clear; while there is some consensus regarding some energy sources, others are shrouded in uncertain outcomes. Generally, on the supply side, the evidence points to a small impact, but the effect varies by location and energy source, with some large effects occurring in some places and with particular energy sources. Given that developing economies such as those in Africa are likely to suffer the most from the adverse effects of climate change, and with the problem of energy poverty on the ascendency in Africa, one of the immediate benefits of limiting global warming to below 2°C could be a reduction in energy poverty, which is known to be linked to other socioeconomic characteristics such as health, education, incomes, and gender equality.

4. Conclusion and implications for policy

This report reviews the patterns and trends of the impact of climate change on socioeconomic indicators, including economic growth, agricultural productivity, poverty, food security, health, water resources, and the energy sector. The data originate from previously published works that provide quantitative assessment of the future impacts of climate change on socioeconomic factors.

Different aspects of these factors have been examined in the literature independently by researchers seeking to understand the patterns and trends of climate change effects, but a simultaneous analysis of all these factors is an information gap we noticed in the literature. Because there is considerable consensus around the fact that developing economies, particularly those in Africa, will suffer the most from the risks presented by climate change, this report focuses on developing economies, with some bias toward African economies. While every attempt was made to review all relevant literature, some information could not be included in this work because of issues such as subscription charges. Therefore, we are cautious in claiming that the information presented in this report is exhaustive. The following conclusions emerged from this study.

Regarding the GDP effects of climate change, there are likely to be winners and losers. The literature reveals positive gains for developed economies, but only until the medium term, beyond which the positive gain in GDP begins to diminish. For developing countries, the cost tends to outweigh the benefit even in the medium term, and this tendency increases in the long term. In addition, we note that although the predicted impact of climate change on GDP may be minimal at the global level, it is quite substantial at the subregional and country levels in some cases. These spatial variations in the impact of climate change on economic growth are also highlighted in subregional and country-level analyses.

Among the developing regions, Africa is one of the areas that is at most risk from climate change. In Asia, an economic loss of between 1.18 percent and 11 percent of GDP is predicted, while in Africa, the decline in GDP due to climate change ranges from 4 percent to 11 percent in the long term. Studies focusing on Africa reveal a mean and median decline in GDP per capita of 7.12 percent and 4.8 percent, respectively, under global warming, compared to the no-climate-change scenario. Even within Africa, we notice important heterogeneities in the impact of climate change on GDP. Areas in the west and east of Africa are identified as at particularly high risk. Within these areas, Ghana, Togo, Côte d'Ivoire, Mauritius, Malawi, and Mozambique appear to be some of the countries at highest risk over the medium to long term. Generally, both global and regional-level studies project that climate change effects on GDP are likely to be stronger in the long term (2100) than in the medium term (2025–2050). In the case of Africa, the economic loss associated with climate change is projected to be marginal until 2050, when the economic loss is expected to grow. Again, while there is some consensus on a global warming tipping point of below or equal to 2°C, in Africa there is no consensus on the tipping point, which may have already passed. The negative effect of climate change is felt above 1°C.

Regarding the effects of climate change on the agricultural sector, studies agree that this sector is most vulnerable to the threat of climate change. Food insecurity and loss of farmland value are some of the likely consequences of future global warming patterns in the agricultural sector. There is general agreement that while rising temperatures reduce crop yield and productivity, an increase in precipitation levels will increase crop yield in the future. In the case of the impact on rice yield, the evidence seems conclusive, and major producing countries are likely to suffer more due to climate change. However, in the case of crops such as maize, sorghum, and millet, the evidence appears very scattered, with no definite pattern. Interestingly, both developing and developed economies risk a reduction in crop yield due to climate change. However, the incidence seems greater among developing economies, particularly those in Africa.

Regional-level studies suggest that climate change could cause crop yield changes of between –2.9 percent and –18 percent in Africa, compared to +1 percent and +14 percent for Latin America and –0.6 percent and –10.8 percent for the rest of the world by 2030 and 2050, respectively. Climate change is likely to aggravate food insecurity more in the long term than in the medium term. Crop yield reduction is predicted to range from 2.9 percent to 5 percent by 2030 but from 6.8 percent to 18 percent after 2050. In Africa, West Africa and East Africa are highly risk-prone areas. The type of crop and location play a critical role in how climate change influences crop yield. We note that different crops may exhibit different resilience levels to climate change based on their location. This is true, for example, of maize and sorghum in Africa. This illustrates the role that spatial dynamics play in understanding the effects of climate change on yields. Rainfed crops are likely to be more affected than irrigated crops. The general prediction of lower crop yields in the agricultural sector is expected to cause crop price inflation of 10–100 percent.

The evidence on the impact of climate change on farmland value appears to be very conclusive, with studies predicting a decline in farmland value with rising temperatures and a rise in farmland value with rising precipitation levels. The predicted decline in farmland value is larger for small landholdings than for large landholdings. In addition, we note that the impact is lower in the medium term than in the long term.

The consequence of lower agricultural productivity due to climate change is an increase in the number of people facing extreme hunger, suffering from undernourishment, and generating less income. A significantly larger number of people are likely to suffer from extreme hunger if global warming is not contained. The incidence of this problem is predicted to be higher in developing countries than in developed economies. Among developing economies, Africa is likely to suffer the most from hunger. The literature revealed that more than 200 million people risk experiencing severe hunger due to climate change in Africa in the medium to long term. In addition, future climate change is likely to increase the prevalence of undernourishment, particularly in Asia, Latin America, and Africa. Crop revenues are also at risk due to climate change. Projections show that more than 30 percent of crop revenues could be lost due to climate change in developing countries. As most people in the developing world depend on the agricultural sector for their livelihoods, this indicates that a significant number of people risk being pushed into poverty. The literature estimated that poverty will be 20–30 percent higher in Africa in a climate change scenario compared with a no-climate-change scenario.

Climate change is also affecting the hydrological cycle, altering the quantity, and timing of stream flow as well as groundwater, freshwater, and precipitation levels. These effects are noted across regions and countries but with some degree of heterogeneity. In Asia, the risk of flooding dominates the climate change impact rather than threats to irrigation systems. However, in Africa, the risk of water shortage dominates, and this risk is projected to escalate under severe climate change scenarios. Climate change is likely to push a significant number of people (more than 50 million) into water stress.

The health effects of climate change are also significant, particularly in developing economies. There is general agreement on the role of climate change in increasing disease spread and mortality. The impact depends on the period and severity of climate change. The negative impact of climate change on health is greater under severe climate scenarios than under less severe climate scenarios. In addition, the negative impact on health looks substantial in the long term. Economies with very weak health systems are likely to be hardest hit by climate change. The health damage caused by climate change could exceed US$2 billion by 2030.

Finally, climate change is a threat to energy security, particularly in developing economies. The effect is more obvious on the demand side, where there is general agreement that global warming will increase energy consumption. Regarding the supply side, however, the evidence is mixed and depends on the location and energy source. There is general agreement on the negative effects of climate change on the generation potential of some energy sources, such as solar, wind, and thermal, but there is no consensus on the potential effect of climate on the generation potential of other energy sources, such as hydropower and bioenergy. Particularly for solar energy, the impact of climate change is minimal.

In summary, this review has provided evidence of the effects that climate change could have on a variety of socioeconomic indicators. There will likely be winners and losers, most probably in the medium term, but in the long term all economies (both developing and developed) might be on the losing end. We note that the literature provides varied results in terms of both the spatial and temporal dynamics of the effects of climate change on socioeconomic indicators in developing economies. The underlying reason for this is the varied initial conditions (temperature, wealth, disease burden, sectoral output, etc.), model assumptions, and estimation techniques adopted in these studies. Across all indicators, the adverse effect of climate change is confirmed to be larger in developing economies, particularly in Africa, than in developed economies. These spatial heterogeneities are an indication that the design of climate adaptation interventions should seriously consider the local context. These heterogeneities also imply that even among the most affected regions, such as Africa, there are priority areas. Thus, in designing climate adaptation measures, priority should be given to these most affected areas.

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