USAID
FROM THE AMERICAN PEOPLE

FREDERICK S. PARDEE CENTER
FOR INTERNATIONAL FUTURES
JOSEF KORBEL SCHOOL OF INTERNATIONAL STUDIES
UNIVERSITY of DENVER

RESEARCH TECHNICAL ASSISTANCE CENTER

November 2021

The Future of Food Security in the Wake of the COVID-19 Pandemic

Willem Verhagen, David Bohl, Mallory Cannon, Andres Pulido, Audrey Pirzadeh, Iris Nott, Jonathan D. Moyer.

This report is made possible by the generous support of the American people through the United States Agency for International Development (USAID) under the terms of contract no. 7200AA18C00057, which supports the Research Technical Assistance Center (RTAC). This report was produced by the Frederick S. Pardee Center for International Futures at the University of Denver under the RTAC contract. The contents of this report are the sole responsibility of RTAC and NORC at the University of Chicago, and do not necessarily reflect the views of USAID or the United States Government.

Acknowledgments

Many people have contributed to this report. We would like to thank David Laborde, James Thurlow, and Sherman Robinson of the International Food Policy Research Institute; Vasilis Tsiropoulos, Cigdem Aslan, Cedric Okou, Christoph Lakner, and Daniel Gerszon Mahler of the World Bank; Susannah Hares of the Center for Global Development (CGDEV); Prachi Srivastava of the University of Western Ontario; and Nina Weisenhorn and Samantha Alvis of the United States Agency for International Development (USAID) for their contributions to the scenario development and their feedback on drafts of the manuscript. We would also like to thank Chris Hillbruner, Anthony Sperber, and Craig Jolie of USAID, Alexandre Monnard, and Gabriela Alcaraz Velasco of NORC at the University of Chicago for their input into the analysis and results of the report, as well as many other colleagues from USAID and NORC for their feedback on drafts and for their specific contributions on content and layout. Finally, many people at the Frederick S. Pardee Center for International Futures at the University of Denver contributed to the report, with special thanks to José Solórzano Arevalo (lead model development), Mohammad Irfan and Barry Hughes (participation in the expert meetings), Collin Meisel and Beth Anne Card (statistical model on child stunting and coefficient of variation, and visualizations), Yutang Xiong (data management), and Adam Szymanski-Burgos, Cory Vandenberg and Henry Valuck (visualizations).

Research Technical Assistance Center

The Research Technical Assistance Center (RTAC) is a network of academic researchers generating timely research for USAID to promote evidence-based policies and programs. The project is led by NORC at the University of Chicago in partnership with Arizona State University, Centro de Investigación de la Universidad del Pacifico (Lima, Peru), Davis Management Group, the DevLab@Duke University, Forum One, the Institute of International Education, the Notre Dame Pulte Institute for Global Development, Population Reference Bureau, the Resilient Africa Network at Makerere University (Kampala, Uganda), the United Negro College Fund, the University of Chicago, and the University of Illinois at Chicago.

Suggested Citation

Verhagen, W. et al., 2021. The Future of Food Security in the Wake of a Global Pandemic. Report. Research Technical Assistance Center: Washington, DC.

Cover Photo Credit: Kapil Neupane, Feed the Future Nepal Knowledge-Based Integrated Sustainable Agriculture in Nepal (KISAN) II, USAID.

Acronyms and Abbreviations

CAR	Central African Republic
CIS	Commonwealth of Independent States
CLPC	Calories per Capita
CO_2	Carbon Dioxide
CP	Current Path Scenario
CV	Coefficient of Variation
FAO	Food and Agriculture Organization of the United Nations
GDP	Gross Domestic Product
HAZ	Height-for-Age Z-Score
IFs	International Futures
IMF	International Monetary Fund
MDER	Minimum Dietary Energy Requirement
MENA	Middle East & North Africa
MH	Million Hectare
NC	No-COVID Scenario
OECD	Organization for Economic Cooperation and Development
PoU	Prevalence of Undernourishment
PPP	Purchasing Power Parity
RCP	Representative Concentration Pathway
SAM	Social Accounting Matrix
SSP	Shared Socioeconomic Pathway
SD	Standard Deviation
UN	United Nations
UNCCD	United Nations Convention to Combat Desertification
UNESCO	United Nations Educational, Scientific and Cultural Organization
UNICEF	United Nations Children's Fund
UP	Unequal Paths Scenario

USAID	U.S. Agency for International Development
USDA	United States Department of Agriculture
WASH	Water, Sanitation and Hygiene
WATSAN	Water and Sanitation
WFP	World Food Programme
WHO	World Health Organization
WTO	World Trade Organization

Executive Summary

Introduction

A large share of the global population today is food insecure, with 10.9 percent of the global population undernourished in 2019 and 23.0 percent of children under five affected by stunting. Safe and affordable access to a diverse, nutritious diet is a basic human need and human right, and food security is embedded in the much broader concept of human development, with linkages to economic growth, household income, environmental sustainability, inequality, child mortality, education, and access to safe water and sanitation. Evaluating progress toward eradicating food insecurity requires not only quantifying food security today but assessing the future of food security over the next decades.

The COVID-19 pandemic has already changed existing patterns of food security, but we have limited understanding of how this global crisis may affect food security in the future. Historically, economic, environmental, and conflict-related crises tend to worsen food security directly, with measurable lasting, sometimes cascading, effects over time. The COVID-19 pandemic is unlikely to be an exception. Initial estimates suggest that 83 to 155 million more people around the world became undernourished in 2020, and child undernourishment and child mortality also rose dramatically. Studies so far have provided little information on the expected magnitude and pathways of the pandemic's long-term impact on food security.

Methodology

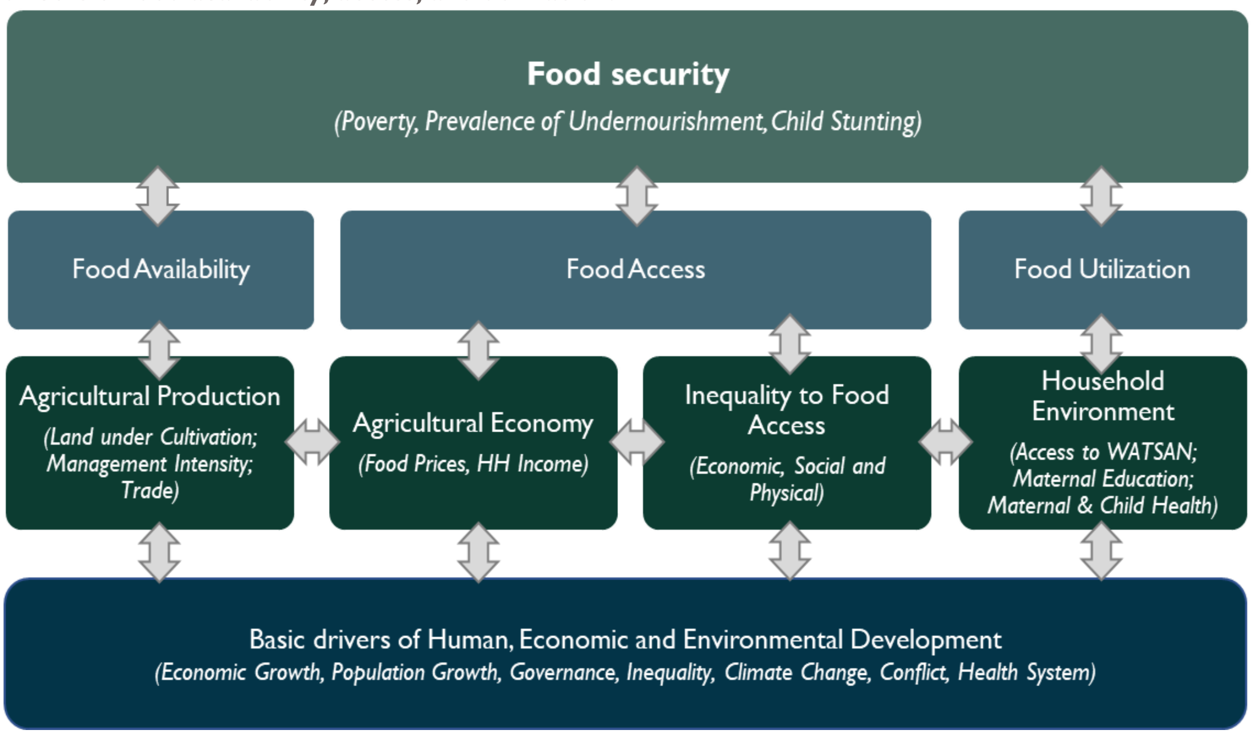
In this report we use a scenario approach to assess how COVID-19 may affect food security for the next two decades, mapping potential effects of the pandemic in 185 countries to the year 2040. We use the International Futures (IFs) model, a global integrated assessment tool, to operationalize scenarios related to the impact of COVID-19 on development. We use these scenarios to quantify the potential range of food security impacts both globally and across ten regions of the world.

We develop two scenarios to assess the effects of COVID-19 on food security out to 2040. We model the effects of COVID-19 on long-term food security for these scenarios, mostly from 2020 to 2022, with some longer-lasting effects. These scenarios include changes to economic growth, income inequality, food access, government finances, and educational attainment. The COVID-19 *Current Path* scenario is our baseline scenario and is based on 2020 to 2022 GDP growth rate estimates developed by the International Monetary Fund (IMF). The COVID-19 *Unequal Paths* scenario is more pessimistic, describing a world in which pandemic effects are predominantly felt by vulnerable countries. In the *Unequal Paths* scenario, GDP growth is further reduced between 2020 and 2022, inequality worsens in countries with limited government capacity, and the effects of rising government debt fall particularly hard on countries that had low levels of debt sustainability prior to the pandemic. We also develop a counterfactual *No-COVID* scenario, projecting how food security is likely to have developed if the COVID-19 pandemic had not occurred.

Conceptualizing and Measuring Food Security

Our conceptualization of food security includes aspects of food availability, food access, and food utilization (Figure 1). To assess changes in food security over time, we model different aspects of this conceptual framework, including the agricultural production system, agricultural trade, household income and consumption of food, caloric intake, and distribution thereof within countries, trends in parental education, and access to water and sanitation (WATSAN). These variables are themselves driven by variables representing demographics, economic growth, climate change, health, and other distal drivers of development.

Figure 1: Conceptual framework for long-term assessments of food security, distinguishing between drivers of food availability, access, and utilization.



Note: The arrows in this figure depict feedback loops between the individual components. The conceptual framework focuses on long-term trends in food security and thus does not account for effects of climate change, conflict, and other factors to volatility in food production, prices, and other drivers.
Source: Authors' elaboration.

Food security is a multidimensional concept that impacts humans in direct ways. According to the Food and Agriculture Organization (FAO), "Food security exists when all people, at all times, have physical and economic access to sufficient, safe and nutritious food to meet their dietary needs and food preferences for an active and healthy life" (World Food Summit 1996). Given this multidimensionality, we focus on three outcome indicators that capture the effects of changing patterns of food security on human development, particularly of the most vulnerable populations. We measure outcomes using extreme poverty, prevalence of undernourishment, and child stunting.

Results

COVID-19 and Poverty

COVID-19 is estimated to have increased extreme poverty in 2020 by 101.9 million people (in the *Current Path* scenario) to 118.3 million people (in the *Unequal Paths* scenario), relative to a *No-COVID* scenario.[1] In 2019, 687 million people were estimated to live on less than $1.90 per day. Before COVID-19 (*No-COVID* scenario), this number was expected to fall to 682 million in 2020. COVID-19 is projected to result in the first rise of global poverty in the last decade, with the *Current Path* scenario estimating 784 million people in poverty and the *Unequal Paths* scenario resulting in an increase to 800 million people in 2020.

By 2040, the world is projected to make progress on eradicating extreme poverty. The prevalence of extreme poverty is projected to drop from 10.1 percent in 2020 to 7.2 percent in 2040 in the *Current Path* scenario. This is equivalent to a drop from 784 million people in 2020 to 660 million people in 2040.

However, COVID-19 may cause a persistent increase in extreme poverty, leading to a six to thirteen-year setback relative to a *No-COVID* scenario. By 2040, COVID-19 will lead to an increase in global poverty of between 18.5 and 35.2 percent, or an estimated 103.9 to 198.3 million people, relative to a *No-COVID* scenario. While all regions are projected to experience an increase, the largest occurs in sub-Saharan Africa and Southern Asia. In sub-Saharan Africa, increases in poverty from COVID-19 varied between 27.8 and 34.6 million people in 2020, and are projected to grow to 55.3 to 113.8 million people by 2040. For Southern Asia, increases in poverty from COVID-19 had larger immediate effects in 2020 (53.0 to 59.2 million people) but less pronounced longer-term effects (22.8 to 43.1 million people in 2040).

COVID-19 impacts extreme poverty through reductions in household income and shifts in the distribution of income. Poverty is most directly driven by changes in economic growth and household income, coupled with changes in income distribution. COVID-19 lowered GDP growth in 2020, followed by a projected recovery in 2021 and 2022. For nearly all countries, this is projected to result in lower economic output from 2023 through 2040 relative to a world without COVID-19. In addition, we assume a one to two percent rise in inequality in the scenarios. While the effect of COVID-19 on inequality is uncertain, studies of previous shocks and pandemics have highlighted that inequality tends to be higher five years after an initial shock. The increase in poverty is especially pronounced in sub-Saharan Africa and Southern Asia because of the growing number of poor and vulnerable households in those regions. This rise in between-country inequality because of COVID-19 is further underlined with the *Unequal Paths* scenario, where we simulate an even greater shock, disproportionately impacting more vulnerable countries. Although only a subset of countries experiences more severe impacts in this scenario, the rise in poverty from COVID-19 almost doubles.

---

[1] At the time of analysis, no data for 2020 was available that could fully capture the effects of COVID-19 on global extreme poverty, undernourishment, or child stunting. Data collection for these indicators strongly depends on household surveys, which have been largely suspended due to COVID-19. This means that for 2020, the analysis strongly relies on model-based estimates to understand the effects of the pandemic on human well-being indicators at the global level.

COVID-19 and Undernourishment

COVID-19 is estimated to have increased undernourishment in 2020 by an additional 48 to 54 million people, relative to a *No-COVID* scenario[2]. The rise in undernourishment is estimated to be less than the rise in poverty. This is because even as household incomes decrease, some households can maintain caloric intake by spending a larger share of their income on food and by shifting diets from vegetables and meat toward staple foods. In 2019, undernourishment was estimated to affect 836 million people. In the absence of COVID-19, we expected this to fall to 828 million in 2020. However, COVID-19 is estimated to increase undernourishment to 877 million in the *Current Path* scenario and 882 million in the *Unequal Paths* scenario.

COVID-19 is projected to result in a persistent increase in undernourishment, leading to a four- to eight-year setback in lowering undernourishment by 2040, relative to a *No-COVID* scenario. By 2040, the world is projected to make progress on lowering the prevalence of undernourishment for all scenarios, but COVID-19 slows this progress. In the *Current Path* scenario, the prevalence of undernourishment is projected to fall from 11.3 percent in 2020 to 8.6 percent in 2040. In the *Unequal Paths* scenario, the prevalence of undernourishment is also projected to drop from 11.4 percent in 2020 to 9.1 percent in 2040. In absolute values, the number of people living under the minimum dietary energy requirement in 2040 in the more pessimistic *Unequal Paths* scenario (837.1 million) exceeds the number prior to COVID-19 in 2019 (836.0 million). This is the result of both slower progress in eliminating hunger and growing populations in the most food insecure regions of the world.

COVID-19 is slowing down progress toward eradicating undernourishment in Southern Asia and sub-Saharan Africa. In 2020, the population of undernourished people in sub-Saharan Africa is estimated to have grown by 8.3 (in the *Current Path* scenario) to 9.6 (in *Unequal Paths* scenario) million. In Southern Asia the number of undernourished people is estimated to have grown by between 21.5 and 23.6 million. By 2040, these regions are projected to continue to experience the largest impact of COVID-19 on undernourishment, with increases of between 13.8 and 30.9 million people in sub-Saharan Africa and between 14.4 and 27.0 million people in Southern Asia. To further highlight the disproportionate effect on these two regions, the projected rise by 2040 for each scenario in either sub-Saharan Africa or Southern Asia is larger than the rise in undernourishment across Southeast Asia, Latin America and the Caribbean, the Middle East, and North Africa combined.

As with poverty, COVID-19 is affecting undernourishment primarily through changes in household income, which drive down country-wide caloric demand, and through changes in the distribution of calories within populations. Reductions in economic growth lower household income and country-level agricultural demand. While shifts in household spending and diet can alleviate some effects of COVID-19 on lowering calories per capita, we project a net drop in countries where populations have limited means to cope with shocks. We also assume a rise in the inequality of within-country caloric distribution because of COVID-19. Overall, the future of food security is expected to depend largely on changes in socioeconomic conditions and the associated economic access to food and

---

[2] The food security data used in this report were up to date as of March 2021. Subsequently, FAO revised its methodology and database to assess food security indicators, resulting in a downward revision of historic food security numbers, especially for China. The new data series would shift down projections in our model of the no-COVID scenario and the two COVID-19 scenarios, though general trends remain similar. Given the timing of this revision and the focus of the report on COVID-19 effects, we have not adjusted for this latest revision. An initial exploration suggests that the effect on the results is minor. Absolute numbers decrease, but the relative effects of COVID-19 on long-term food security remain unaltered and the overall insight that COVID-19 slows down progress on eradicating extreme poverty, undernourishment, and child stunting holds.

distribution of calories within populations. COVID-19 is projected to negatively impact both dimensions, by reducing calories per capita and negatively shifting the caloric distribution within populations.

COVID-19 and Child Stunting

COVID-19 is projected to have minimal near-term effects on child stunting, but with increasing effects out to 2040. We estimate that in the *Current Path* scenario child stunting affected 159.6 million children under age five in 2020, a small increase from 159.3 million children in a *No-COVID* scenario. In the more pessimistic, *Unequal Paths* scenario, child stunting is estimated to rise further to 164.4 million in 2020 and continues to rise to eight million additional children in 2025, relative to a *No-COVID* scenario. This forecast is in line with one other forecast on child stunting suggesting an increase of between 1.5 million to 3.6 million children in the 2020 to 2022 period, relative to our projected increase of 1.6 million in the 2020 to 2022 period in the *Current Path* scenario.

Child stunting is affected by changes in caloric demand, coupled with changes in maternal education and access to WATSAN. Caloric demand is affected by COVID-19 directly, but in contrast to undernourishment and poverty, the effect of COVID-19 on WATSAN and adult education levels is expected to increase over time. Children affected by education losses today are likely to have lower levels of education in the future, as they become parents. Changes in government debt and expenditures don't result in direct losses in access to WATSAN, but rather slow down investments in the maintenance and construction of WATSAN infrastructure. These slow onset effects of COVID-19 make clear that the effects of the pandemic on child stunting are unlikely to cease after the virus is contained.

Impacts of COVID-19 on parental education and access to WATSAN are projected to manifest over the next two decades, resulting in a one- to three-year setback in progress on child stunting by 2040. In the *Current Path* scenario, the world is projected to reduce child stunting to 14.9 percent by 2040. In 2020, sub-Saharan Africa and Southern Asia are the regions with the highest rates of child stunting, followed by Southeast Asia, Oceania, and the Middle East and North Africa. Progress on eradicating child stunting is especially strong in Southern Asia, falling from 33.6 percent in 2020 to 18.4 percent in 2040, and to a lesser extent in sub-Saharan Africa, dropping from 32.9 percent in 2020 to 20.1 percent in 2040. By 2040, child stunting rates are projected to reach 14.5 percent in a *No-COVID* scenario and 14.9 percent to 15.4 percent in the *Current Path* and *Unequal Paths* scenarios, respectively. This is equivalent to an increase due to COVID-19 of between 4.0 and 7.8 million children in 2040.

Climate, Conflict, COVID-19, and Food Security

Climate change affects food security directly through impacts on food availability, economic growth, and food utilization. Climate change drives shifts in temperature and precipitation, changing the biophysical conditions for cultivating crops. Its impacts differ between regions, and the role of CO_2 fertilization features prominently. Changes in production have indirect effects on food access by altering food prices and household income from agriculture. A more direct effect of climate change on food access operates through reductions in economic growth across all sectors, with further reductions in household income. Changes in household income have consequences for both extreme poverty and food access. Lastly, climate change could alter the spread of communicable diseases, such as malaria and diarrheal disease, increasing vulnerabilities related to food utilization. The effects of climate change on declining food security are projected to occur mainly in sub-Saharan Africa and Southern Asia.

Conflict affects food security through impacts on food availability, food access, and food utilization. Even the threat of conflict can be enough to shift crop production toward staple crops and smaller agricultural livestock. During conflict, the effects on food availability, access, and utilization are most pronounced. Sometimes, limiting food access is utilized as a weapon of war. This results in an important dimension of inequality, with conflict disproportionately affecting availability, access, and utilization for females and children, as well as for displaced populations. After conflict ceases, longer-term effects on economic growth and reduced agricultural production often remain, negatively affecting food security several years after the end of a conflict.

The future of climate change and conflict is characterized by uncertainty, both around the extent of the occurrence of climate change and conflict and their impact on food security. The impact of climate change is still highly uncertain, with projections ranging from a five-degree average surface temperature increase to less than a one-degree increase (relative to an average global temperature from 1986 to 2006). Not only is the extent of climate change uncertain, but its effects on food security are strongly dependent on model assumptions and CO_2-fertilization effects. The distribution of future conflicts is also characterized by great uncertainty, though most baseline scenarios project a reduction. Some studies highlight the regional distribution of future conflicts, with possible increases in sub-Saharan Africa and South Asia, two areas that struggle with food insecurity.

Comparing risk factors is challenging, but generalizations are possible. Studies do not exist that allow for a simple comparison of the impact of COVID-19, climate change, and conflict on outcome indicators associated with food security. But general conclusions are possible:

a) *The pathways through which each risk factor impacts food security are distinct.* COVID-19 is primarily a food access issue, though it does present additional risks to other drivers, while climate change and conflict more directly impact multidimensional aspects of food supply, access, and utilization.

b) *Our understanding of the future impact of these risk factors is uncertain.* COVID-19 and conflicts have been experienced recently, but conflict has been experienced throughout human history. Future patterns of both risk factors are difficult to predict. And while the effects of climate change are beginning to be felt, its most significant risks have yet to fully manifest.

c) *The geographic distribution of these risk factors varies.* Both climate change and COVID-19 are global events with differential localized impacts. Conflict, on the other hand, tends to be localized and particular.

Future of socioeconomic development matters. COVID-19, climate change, and conflict will each manifest in unique ways, impacting food security and human development. But research shows that the future of human development—levels of economic growth, food availability, economic interdependence, and demographic change—will be more significant drivers of our ability to adapt to these challenges.

Conclusion

The analysis presented here suggests that COVID-19 has set back global progress toward eliminating extreme poverty, undernourishment, and child stunting. The world is projected to continue to make gradual progress in improving indicators and drivers of food security, but COVID-19 will slow down this progress. The effects primarily operate through reducing food access from lower household incomes and rising inequality in the distribution of caloric intake and income. Reduced access to safe water and sanitation and lower levels of education will further aggravate the effects, the results of which are likely to materialize over the next decade. All these effects are projected to disproportionally affect the most food insecure regions in the world today (Southern Asia and sub-Saharan Africa).

The world is projected to continue to make progress in improving food security and human well-being, though that progress will be unevenly distributed. Many countries were not on track to meet international goals for improved food security, and COVID-19 has made reaching these goals even more ambitious. The pandemic further underscores the need to push for improving socioeconomic conditions, particularly in sub-Saharan Africa and Southern Asia. Projected progress toward the elimination of hunger will be multidimensional, requiring improvements in food availability, access, and utilization. Further work toward eradicating food insecurity will primarily rely on raising food access by improving household incomes and caloric demand and by reducing inequality of household income and food access.

Table of Contents

List of Tables

List of Figures

1. The future of food security in the wake of the COVID-19 pandemic

Every human being needs safe and affordable access to a diverse, nutritious diet. However, this is not a reality for over 690 million people globally, and in 2019, 21.3 percent of children suffered from stunting (Baquedano et al. 2020; FAO et al. 2020; UNICEF, WHO, and World Bank Group 2020). In this context, what will the progress on food security be by 2040, and how will COVID-19 affect food security in the long-term? This report uses scenarios to quantify changes in food security at the country level and explores how the COVID-19 pandemic affected food security in 2020 and how it is projected to affect it out to 2040.

Understanding the impacts of the COVID-19 pandemic on food security requires understanding the long-term trends and drivers of food security. Food security is a multidimensional concept deeply ingrained in agricultural production systems, international food trade, economic access to food, safe food preparation and utilization, access to safe water and sanitation, climate change, conflict, and land degradation (FAO et al. 2020; Hasegawa et al. 2018; Janssens et al. 2020b; Moyer et al. 2020; Mueller et al. 2012; UN Convention to Combat Desertification 2017; van Ittersum et al. 2016; van Meijl et al. 2020). Understanding the long-term future of food security requires conceptualizing economic, human, and environmental development and the interactions between these systems. However, too often long-term forecasts focus almost exclusively on agricultural supply and how it is affected by climate change. This limits our understanding of the future of food security and fails to provide a multidimensional lens for envisioning alternative policies and actions to alter this future.

Economic, environmental, and human security crises tend to worsen food security immediately, while also creating cascading effects across time (FAO 2009; Gates et al. 2012b; Hasegawa et al. 2018; Verwimp and Muñoz-Mora 2018; Vilar-Compte et al. 2015; Zhao et al. 2017). The COVID-19 pandemic is unlikely to be an exception. Initial estimates are that an additional 83 to 155 million people became at risk of hunger in 2020 (Baquedano et al. 2020; FAO et al. 2020) and there was increased risk of rising child undernourishment and mortality (D. Headey et al. 2020; Osendarp et al. 2021). Long-term projections of food security initially quantified the effect of COVID-19 through projected reductions in GDP (Baquedano et al. 2020; FAO et al. 2020). Today, our understanding of the long-term effects of COVID-19 also include growth in government debt, rising inequality, and education losses (IMF and World Bank 2021; UNESCO 2021; World Bank 2021c). Despite these efforts, we only have a partial understanding of how COVID-19 may alter food security outlooks beyond the pandemic and the underlying interconnected drivers.

In this report, we use the International Futures (IFs) model to explore the future of global food security at the country level out to 2040. Specifically, we develop a set of scenarios to quantify the effect of COVID-19 on food security across indicators of extreme poverty ($1.90 per person per day), undernourishment, and child stunting. In Section 2 we provide the conceptual background for this study by defining food security and using literature to assess how COVID-19 is affecting food security in 2020 and from 2020 to 2040. In Section 3 we use this conceptual understanding to develop a scenario framework of the key long-term dimensions of COVID-19 on food security. In Section 4 we quantify trends in extreme poverty, undernourishment, and child stunting at the global and world region level, and the effect of COVID-19 on these trends. In Section 5 we provide a deeper understanding of how COVID-19 is affecting drivers of food access, availability, and utilization. Lastly, in Section 6 we contextualize the results by comparing the pathways and magnitude of COVID-19 to the effects of climate change and conflict. Overall, this report provides a multidimensional overview of the future of food security and its underlying drivers out to 2040—and the extent to which COVID-19, conflict, and climate will shape this future.

2. Understanding food security and the impact of COVID-19

Purpose: This section provides the conceptual underpinning for studying food security. It focuses on how to define food security, how to measure it, and how to identify its long-term drivers. Special attention is given to the effects on food security of COVID-19, with the second part of the section focusing on how COVID-19 is affecting food security and its underlying drivers. This section provides the conceptual underpinning for the analysis and results presented later in the report.

2.1 What is food security and what are its drivers?

Food security is a multidimensional concept that includes food availability, food access, and food utilization. These three pillars of food security (Figure 2) are reflected in the definition from the Food and Agriculture Organization of the United Nations (FAO):

> Food security exists when all people, at all times, have physical and economic access to sufficient, safe and nutritious food to meet their dietary needs and food preferences for an active and healthy life. (Word Food Summit 1996)

Food security in a given country also consists of three interconnected pillars. The first pillar, *food supply* or *availability*, consists of domestic production, food imports and exports, and food stocks. Policies aimed at improving food availability affect land under cultivation, agricultural management intensities, crop composition, and agricultural trade. The second pillar, *food access*, is the ability to access the food available, which can be hampered due to economic, physical, and social constraints. It is defined by the interplay of household incomes and changing food prices and economic inequality (e.g., poverty), social inequality (e.g., gender), and physical inequality (e.g., market access, urban-rural divide). Adequate food availability at the national or international level does not guarantee adequate food access at the level of households and individuals, and food access policies focus on making food available to all. The third pillar, *food utilization*, is the ability of the body to make the most of the nutritional value of food. Country-level indicators of human development, coupled with safe household environments, jointly shape food utilization, which includes access to health care and WATSAN, maternal education, maternal and child health, breastfeeding practices, and food preparation. Even with enough food available at the household level, food utilization may result in decreased food security within households, especially for members with specific food needs, such as

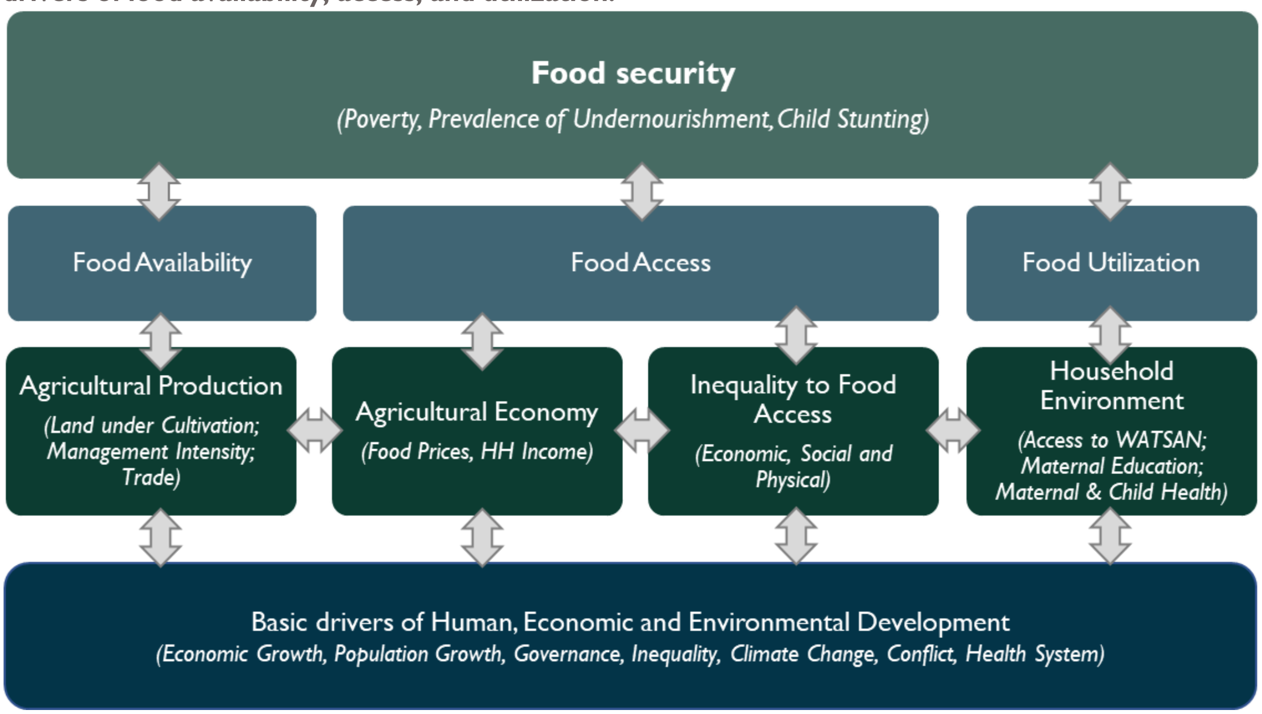
Food security insight

Long-term changes in food security are determined by changes in trends in food availability, access, and utilization.

infants and young children, pregnant or lactating women, and sick or elderly household members (World Food Programme 2009).

Together, these three pillars shape food security over time, which is dynamic. *Stability in food security* occurs when there is adequate food *availability*, *access*, and *utilization* over time. Here, we focus primarily on the dimension of chronic long-term food insecurity. But food insecurity can also occur within and across years due to seasonal and transitory food insecurity (FAO 2008). Especially important is *volatility*, in relation to risks to food security through climate change, conflict, and now, COVID-19. This report looks at projections of food security over the next two decades, measured at yearly intervals. It focuses primarily on chronic, long-term food insecurity across the dimensions of availability, access, and utilization. While COVID-19 today is having a shock-effect on food security, our goal is to identify the potential effects of COVID-19 on long-term risks to food security and then to quantify the chronic, longer-term changes to the system of food security.

Figure 2: Conceptual framework for long-term assessments of food security, distinguishing between drivers of food availability, access, and utilization.



Note: The arrows in this figure depict feedback loops between the individual components. The conceptual framework focuses on long-term trends in food security and thus does not account for effects of climate change, conflict, and other factors to volatility in food production, prices, and other drivers.
Source: Authors' elaboration.

The multidimensional nature of food security requires a host of measurement indicators. To better understand the writing and lens used throughout this report, it is important to define food security[3], its indicators, and related terms (Box 1 – Indicators and definitions of food security).

[3] Throughout the report, we distinguish between three related broad terms, namely *food security*, *malnourishment*, and *undernourishment*. Food security is closely related to malnourishment and undernourishment. *Malnourishment* generally occurs in the absence of sufficient, safe, and nutritious access to food. It pertains to both a state of deficient calories or nutrients and the excess intake of calories, which can lead to overweight and obesity. Undernourishment is a subcomponent of malnourishment, focused only on the lower end of food distribution, and is marked by a state of deficient calories and nutrient intake. Given our focus on food (in)security, we center the report around indicators of undernourishment.

Box 1 – Indicators and definitions of food security.

Food security can be quantified using a diverse set of underlying indicators. Here we primarily focus on population level indicators that can be projected over long-time horizons. While the indicators described below cover a range of interrelated food security issues, we acknowledge that food security is much broader and for example also relates to issues on child wasting, nutrient intake and dietary quality. To aid the reader, we specifically define each indicator below.

Extreme poverty: The population in a country living on less than $1.90 a day. Extreme poverty and food security are closely related, with low-income levels being a key determinant of population wide undernourishment and a core indicator of households' ability to afford and access a sufficient, diverse, and healthy diet. In addition, strong connections between extreme poverty and other indicators of food security exist for child undernourishment, child stunting, child wasting, and micronutrient intake and dietary quality.

Prevalence of undernourishment: The population in a country not meeting the minimum daily energy requirement (Baquedano et al. 2020; FAO et al. 2020). Prevalence of undernourishment (PoU) relates to aspects of food availability (caloric availability) and economic and physical access to food and inequality therein (coefficient of variation). The indicator considers the available calories per capita and their distribution and a threshold value for the minimum dietary energy requirement, which is based on the population structure of a country. The PoU can be quantified in percentage of population or absolute numbers. It is the most general measure used in policy documents and academic literature for assessing long-term trends in population-wide food security. We quantify the effect of COVID-19 on undernourishment over time. Undernourishment is an indicator that can be directly linked to caloric intake, and therefore is a direct measure of food security.

Child stunting: The population in a country under the age of 59 months with a low height-for-age ratio, more than two standard deviations (<-2 SD) below the WHO Child Growth Standards median (FAO et al. 2020). Child stunting is more prevalent than underweight children[1], or child wasting[1], and is often seen as a priority indicator in food security programs and research. Child wasting and underweight children can result in future child stunting, due to temporal lags from declines in food security (first wasted, then stunted; see Schoenbuchner et al. 2019) and shared drivers. From the rate of child stunting, it is possible to calculate the percentage of the adult population in a country 15 years of age and older who have suffered from child stunting. This is called *adult stunting* in the IFs model. Within the IFs model, *adult stunting* is used mostly as a negative effect on the labor force in a country, literally stunting economic growth. In the results section of this report, we report on child stunting as a primary indicator, and we quantify the impact of COVID-19 on it in 2020 and in 2040. Child stunting is based on an anthropometric indicator (height-for-age), rather than caloric intake, and thus can be best understood as an indirect indicator for food security.

The drivers of food security are interconnected and relate to broader drivers of human development. The future of food security is not subject solely to improving agriculture, changing agricultural trade, raising household incomes, or fighting climate. Rather, it will be impacted by progress in broader human development. This requires careful balancing acts by policymakers because policies aimed at improving one pillar can negatively affect others and unintentionally reduce food security.[4] To manage those trade-offs, and to understand how they shape the long-term future of food security, we begin with a discussion of some core underlying drivers.

2.1.1 Availability

Drivers of food availability include land under cultivation, yields, and international patterns of trade. Land is a scarce resource, and a large share of suitable land for agriculture is already under cultivation. Growing, and more affluent, populations who have concerns about climate change, land degradation, and biodiversity will increase demand for land. As those demands change, land will increasingly be a limited resource of competition, and demands for sustainable land management, climate change mitigation, recreational opportunities, biodiversity protection, and food security require careful navigation of trade-offs (Beckmann et al. 2019; Hasegawa et al. 2018; Pittelkow et al. 2015; Phalan et al. 2011; Verhagen et al. 2018). Opportunities for agricultural land expansion exist but are primarily constrained to certain regions of the world, such as the Democratic Republic of Congo or Brazil. Other areas see long-term trends of land abandonment or have already reached their limits of land expansion. For example, land-deprived countries in the Middle East are investing in prime agricultural land in Africa to expand their production potential (The Land Matrix 2021; Schwartzstein 2019), which can simultaneously increase agricultural production and threaten local food security (Müller et al. 2021). In Europe, land abandonment, not expansion, is projected to be a dominant trend in agriculture (Perpiña Castillo et al. 2021; van der Zanden et al. 2017).

Food availability

Food availability is affected by shifts in agricultural production and trade, through changes in land under cultivation, yields, and international patterns of food trade.

Agricultural production can also be expanded through further crop intensification and techniques that lead to higher yields. The potential for doing so varies greatly across regions of the world. In Europe, North America, and increasingly China and other Asian countries, yields are projected to reach biophysical maximums. In other areas, such as sub-Saharan Africa, there is considerable room for yield improvements through adoption of optimal management techniques of crop, land, and water (van Ittersum et al. 2016).

A third important driver of food availability relates to international agricultural trade. Today, many food insecure countries are net importers of food, and the import dependency of many countries in sub-Saharan Africa is expected to rise considerably over the next three decades (Sulser et al. 2015; van Ittersum et al. 2016; OECD and FAO 2020; Hedden et al. 2016). Changes in trade patterns not only drive overall availability but are linked to changes in food prices and economic access to food. For example, lowering food import tariffs and promoting international food trade can improve food security in sub-Saharan Africa (Janssens et al. 2020a), although with potential risks to household incomes from agriculture and food sovereignty. These multiple, sometimes competing, outcomes of trade on availability, sovereignty, and access highlight the need to use a multidimensional concept of food security.

Food availability at the country level will be driven by changes in land use and quality, yields, and international trade. The main trends are highly region-dependent, with some world regions reaching land and yield maxima, while others still have significant room for increasing domestic production. However,

[4] For an example of climate policies and food prices, see Hasegawa et al. 2018.

environmental concerns about climate change and biodiversity may further strain the ability of countries to expand domestic production (Hasegawa et al. 2018; Beckmann et al. 2019; Phalan et al. 2011). Eradicating hunger and meeting the increasing food requirements of growing and generally more affluent populations, while minimizing harm to climate change and biodiversity, is a difficult balance to strike and one that will determine the future of both food security and global environmental change.

2.1.2 Access

Food access is driven primarily by economic factors, in combination with social and physical access to food. In studies projecting mid-21st century food security, much attention has been given to the importance of agricultural production, but recent studies have determined that in fact, future food security is likely to be primarily driven by food accessibility (van Meijl et al. 2020; Hasegawa et al. 2018; Janssens et al. 2020a). For example, a recent study shows that climate change mitigation can have a net positive effect on food availability; but a consequential rise in food prices due to mitigation measures could result in net negative outcomes for food security in 2050 (Hasegawa et al. 2018). The fact is that today, the amount of food produced globally is sufficient to feed the world. Current levels of undernourishment are due, at least in part, to unequal caloric distribution and access. Changes in both food prices and household incomes are likely to continue to be the core determinants of food security (FAO et al. 2020).

The two main determinants of food access are general population level access to calories and the distribution of calories[5] within a population. Increases in access to calories, often measured as calories per capita, are driven by economic growth and population dynamics. A second important driver relates to the distribution of calories within a country, consisting of economic inequality but also social and physical inequality. Economic inequality is a direct driver of poverty and, in the long run, may be fueled by the unequal distribution of education and skill levels.

Social inequality is a broad and diverse issue with varied dynamics surrounding the distribution of goods and burden within a society. In this report we focus on the impact of social inequality on food security for females and children. Females and younger children are at greater risk of having poorer access to food than other members of their households. Lower female labor participation can reduce within-household bargaining power regarding the type of food purchased. In many parts of the world, women are farmers, but often lack the same level of access to resources for agricultural production as their male counterparts (Agrawal 2015). Similarly, women face land tenure rights and other gender and societal inequalities that further challenge their access to the same resources available to their male counterparts (Higgins et al. 2018; Owoo and Boakye-Yiadom 2015). Land tenure rights are also closely linked to questions of physical access, as many households rely on small-scale agricultural production as a source of household income and direct access to food. An estimated 30 to 34 percent of global food production comes from smallholder farms (Ricciardi et al. 2018).

Food access

Food access is determined by changes in economic, physical, and social access to food, primarily from changes in household income and inequality in access to food.

[5] Here distribution of calories is an indicator of food access, reflecting the deviation from the mean caloric intake for individuals in the population. Distribution of calories thus has primarily to do with differences in economic purchasing power, and not with the physical distribution and transport of food through trade and markets.

Urbanization is another component of physical access to food and has a mixed effect on food security. On the one hand, urbanization may increase physical access to food through infrastructure development and increased market access. On the other hand, low-income and urban populations are more likely to purchase, rather than produce, food and are more susceptible to changes in food prices (Szabo 2016). Access in terms of quantity, diversity, and quality of food can significantly differ across urban and rural populations, and trends in urbanization and subsistence farming will determine food security for large swaths of the population.

Overall, changes in food prices, household income, and inequality in access are likely to be the strongest drivers of future food security. In recent years, this relationship has become more complex because rising income levels and decreasing poverty numbers have been met by increased levels of undernourishment, explained by rises in conflict around the globe (FAO et al. 2020). Whether this interruption of the trend between lowering poverty and rising undernourishment is temporary or a "new normal" is an open question for now (Baquedano et al. 2020; FAO et al. 2020) and will be a key determinant of future trends in food security.

2.1.3 Utilization

Drivers of food utilization are manifold and complex, but generally include characteristics of a safe household environment and general trends in access to safe water, sanitation, parental education levels, and access to health care. Though food utilization is connected to all forms of undernourishment, it is an especially significant driver of food security for children. Food utilization is connected to access to safe water, sanitation and hygiene (WASH[6]) and the prevalence of communicable diseases, such as diarrhea (Vaivada et al. 2020; Akseer, Vaivada, et al. 2020). In addition, access to health care, maternal health, breastfeeding practices, a history of childhood stunting for mothers, and fertility rates further determine levels of childhood stunting, wasting, and undernourishment (Stewart et al. 2013; Vaivada et al. 2020; Briend, Khara, and Dolan 2015). A cross-country literature overview highlighted that changes in parental, and especially maternal, education are strongly connected to child undernourishment and stunting and are a prime determinant of childhood mortality (Gakidou et al. 2010; Bhutta et al. 2020; Huicho et al. 2020). Globally, female education levels are on the rise, but only 35 percent of countries are on track to meet Sustainable Development Goal 4 targets on primary and secondary education (Moyer and Hedden 2020). High levels of population growth and fertility rates could further complicate these issues, if access to WATSAN, expansion of female education, and accrual of household assets does not keep pace.

Food utilization

Food utilization is connected to all indicators of food security, but is especially important for child undernourishment, child stunting, and child wasting.

In general, aspects of food utilization have received less focus in long-term studies of food security. Indicators primarily center on PoU without quantifying trends in child undernourishment, wasting, and stunting.[7]

Many drivers fall outside the traditional set of economic, food system, and biophysical drivers used in food security studies and can only be addressed through exogenous scenario assumptions or through a model framework that specifically integrates aspects of broader human development into a food security framework. We will use such an integrated modeling

[6] Child undernourishment is related to access to safe water, sanitation and hygiene (WASH). The latter is difficult to forecast over longer time frames, and therefore we primarily focus our analysis on access to WATSAN. The terms are used interchangeably throughout the report.
[7] See Moyer and Hedden 2020; Moyer et al. 2020 for some notable exceptions.

framework to explore these questions. Not accounting for food utilization and child food security paints an incomplete picture of the future of food security and the policy responses available at the global and national levels.

2.1.4 Dynamics

Trends in availability, access, and utilization do not operate in isolation. Figure 2 highlights some important interconnections between these systems. For instance, agricultural production and trade interact with food prices and household income. Similarly, household income interacts with maternal health and education. More importantly, a wider set of drivers of economic, human, and environmental development interact with the three pillars of food security. For example, economic growth and demographic transition will determine overall demand for food, as well as shifts in diets. Agricultural trade affects both food availability at the national level and food access, through changes in food prices. Similarly, economic and cultural changes will determine dietary shifts, and a less meat-oriented diet can have significant beneficial effects for environmental sustainability (O'Neill et al. 2014).

Environmental changes and interactions within environmental systems also directly impact food security. Chief among these are changes in climate and trends in land degradation, which directly affect food availability, especially in the most vulnerable regions of the world. For example, both land degradation and climate change are expected to have a strong negative effect on food production in sub-Saharan Africa, the Middle East and North Africa and South Asia (Esch et al. 2017; Tai, Martin, and Heald 2014; Liu et al. 2016; Janssens et al. 2020a; Zhao et al. 2017). And changes in biodiversity and supporting ecosystem services threaten the durability and sustainability of the food system (Phalan et al. 2011; Beckmann et al. 2019; Tscharntke et al. 2012). Thus, to determine the future of food security, it is imperative to gain a deep understanding of the interworking of the economy, the environment, and socioeconomic development.

2.2 Measuring food security

Because food security is a multidimensional concept, it must be measured using various indicators. We focus primarily on three core indicators of extreme poverty, the PoU, and child stunting. These indicators were selected using three basic criteria: relevance to the goals and mission of USAID, data availability across countries and time, and the possibility of projecting these indicators over longer time frames. This excludes indicators of food security related to dietary quality and micronutrient intake (see for a discussion on this: Box 3: COVID-19 and dietary quality). While more data is becoming available on these indicators, these data series are still relatively scarce in country and time coverage, and there are very few studies that have attempted to forecast dietary quality over time.

Methodological insight

In this report we quantify long-term trends in food security through extreme poverty, prevalence of undernourishment, and child stunting.

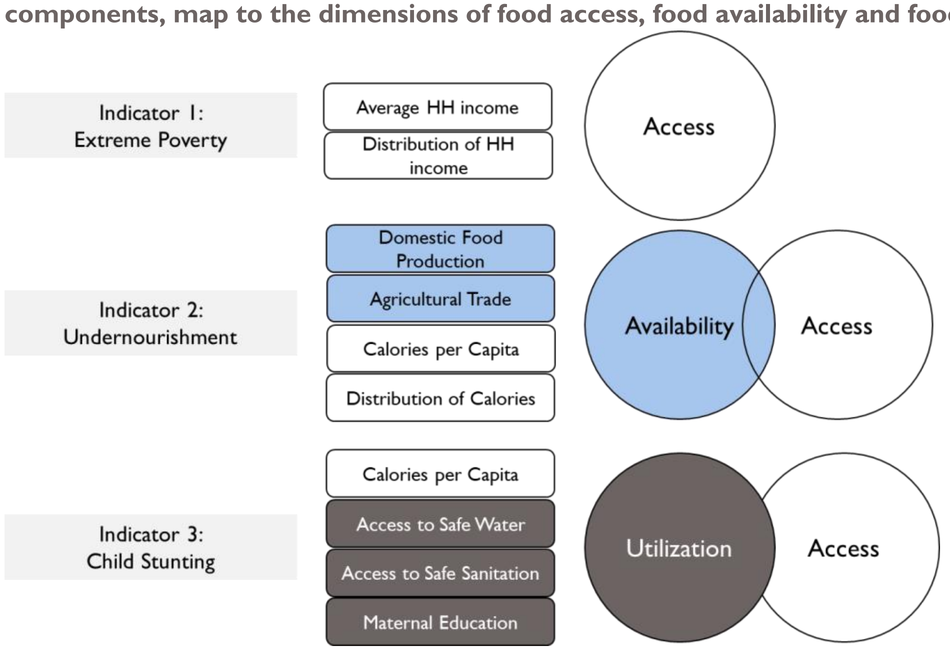
The PoU is a core indicator used in academic publications and policy reports focused on long-term projections of food security, relating food security primarily to issues of food availability and access (FAO et al. 2020; Baquedano et al. 2020; Hasegawa et al. 2018). It also allows for comparisons of the findings in this report to others.

Child stunting is commonly used as a proxy for chronic food insecurity as it reflects an environment that is inadequate for child growth. It has received the most attention in food security programs and academic literature (Onis and Branca 2016; Lloyd et al. 2018; UNICEF, WHO, and World Bank Group 2020; Vaivada, et al. 2020)). Child stunting is correlated with negative future effects on education performance, household income, work capacity, and intergenerational health. In girls, child stunting is linked to lower adult weight and height, resulting in higher risks for complications in future pregnancies (Akseer, Vaivada, et al. 2020; Leroy and Frongillo 2019; C. P. Stewart et al. 2013).[8]

Together these three indicators span the different dimensions of food security. Extreme poverty is linked mostly to the distribution of household incomes and food access. The PoU is primarily determined by a combination of agricultural availability and food access. Child stunting is mostly determined by a combination of food utilization and caloric intake.

The three indicators reflect a multidimensional definition of food security that covers aspects of availability, access, and utilization (Figure 3). Given our focus on the long term, we exclude indicators of food security related to quality and nutrient deficiencies. While relevant to understanding the future of food security, there is currently a lack of understanding of long-term trends and drivers of nutrient deficiencies as they relate to food security. Therefore, this report focuses on long-term projections of food security through quantification of extreme poverty, PoU, and child stunting as core outcome indicators, in combination with their underlying drivers.

Figure 3: Stylized representation of how the food security indicators, and their respective components, map to the dimensions of food access, food availability and food utilization.



Source: Authors' elaboration.

[8] In recent years the forward effects of child stunting have been contested, with authors arguing that forward effects of stunting on economic growth operate through a deficient household environment, which is strongly correlated to childhood stunting, but not through childhood stunting per se (Leroy and Frongillo 2019). As such we talk about child stunting being indicative, not necessarily a pure driver, of long-term development effects. The IFs model does include a forward link of childhood stunting to reduced human capital and economic growth. The authors are critical of a focus on overcoming linear growth retardation in practice and argue for a broader strategy to improve childhood development concerning education, poverty eradication, and undernutrition. The IFs model already links childhood stunting to much broader drivers of human development, and as such, childhood stunting is also represented as a much broader concept related to broader aspects of the household environment.

Extreme poverty is linked mostly to food access, and undernourishment is mainly linked to food availability and access, whereas child stunting is mainly linked to utilization and access. These three outcome indicators span the multiple dimensions of food security.

2.3 How does COVID-19 affect drivers of food security in 2020 and beyond?

The spread of the SARS-CoV-2 coronavirus which causes COVID-19 has disrupted human lives and health systems, and policy responses to curb its spread have had broad effects on economic, socioeconomic, and human development. The pandemic and policy responses to it are affecting all components of food security: availability, access, and utilization. However, the extent to which these components change, and the durability of these effects is not uniform (Table 1). It is therefore helpful to distinguish between the immediate and long-term effects of COVID-19 on food security. From empirical evidence and policy reports, we conclude that COVID-19 is primarily affecting food access, both direct and in the long-term. The effects of food availability from COVID-19 are mostly temporary, whereas effects of food access and utilization tend to persist.

2.3.1 Immediate effects of COVID-19 on food access

The dominant pathway through which COVID-19 is affecting food security is in reducing access to food (Laborde et al. 2020). Access to food is affected physically by lockdowns and worker illness, but more importantly through economic declines from reduced household income. Country-level GDP growth declined in 2020, and while recovery is expected in 2021, neither GDP, GDP per capita nor household income are expected to fully recover in most countries. Countries already experiencing food insecurity have experienced deepening food crises due to the economic shocks of the pandemic, including Haiti, Zimbabwe, and Sudan (Food Security Information Network and Global Network Against Food Crises 2021). A telephone survey in Ethiopia confirmed the challenges faced by households on economic access to food. Only a small portion of households (20 percent) reported having enough savings to cope with declines in household income caused by the pandemic (Abate, Brauw, and Hirvonen 2020).

> **Insights from the literature**
>
> **The primary direct effect of the COVID-19 pandemic on food security is a change in access to food, through shifting patterns of economic growth, household income, food prices, and inequality in income and calories within populations.**

Along with reduced spending opportunities from declining household budgets, access to food is also affected by short-term changes in food prices. Since January 2020, global food prices have risen by 38 percent, with maize prices up 80 percent and wheat prices up 28 percent (World Bank 2021a). This heightens the risk of declines in food security for poor to near-poor households, resulting in reductions in both quantity and quality of nutrition (Akseer, Kandru, et al. 2020; Laborde et al. 2020). For instance, the export price of Thai and Vietnamese rice rose 25 percent between December 2019 and September 2020. This caused an estimated 15 percent fall in rice consumption for the poorest 40 percent of households in in Papua New Guinea (Schmidt, Dorosh, and Gilbert 2021). In the Sahel region of Africa, several countries experienced moderate-to-severe increases in food prices in 2020 as a result of combination of the pandemic, a locust outbreak,[9]

[9] Starting in June 2019 and continuing into 2020, a desert locust outbreak reduced crop production from Eastern Africa and the Horn of Africa (South Sudan) to as far west as India. The epicenter of the outbreak was in Eastern African and the Horn as well as Arabian Peninsula (Yemen, Saudi Arabia).

and rising conflict (World Food Programme 2020c). In Nigeria, price increases of major food crops affected a majority of households in 2020, according to a broad-based survey (World Bank 2020d), However, COVID-19-induced changes to food prices are unlikely to persist after the pandemic is over.

The effects of COVID-19 on economic growth, household income, and income distribution directly impact poverty and undernourishment. The global economy contracted an estimated 3.3 percent in 2020, but is expected to pick up in the next two years, with growth of 6 percent and 4.4 percent projected in 2021 and 2022, respectively (IMF 2021b). This recovery is expected to be uneven, with advanced economies such as the United States seeing stronger growth than low and middle-income countries exacerbating global inequalities (IMF 2021b; World Bank 2021b). Around the world, an estimated 255 million jobs were lost in 2020 relative to the fourth quarter of 2019, due to a combination of unemployment and reduced hours. That is equivalent to 8.8 percent of global working hours, with losses particularly high in Latin America and the Caribbean, Southern Europe, and Southern Asia (ILO 2021). Job losses and underemployment are unequally distributed demographically, with unskilled workers, women, and young workers experiencing more severe losses than other groups (ILO 2021; 2021; Laborde, Martin, and Vos 2021; World Bank 2021b). Similarly, job losses are unevenly distributed across sectors, with higher losses in tourism-related industries, construction, retail, manufacturing, and transportation, as well as the informal sector—contributing to within and across country inequality (ILO 2021; IMF 2021b; World Bank 2021b).

Lockdowns, job losses, decreased remittances, and illness have resulted in lost household income, with a direct impact on poverty. Some countries have been able to contain the impacts of the pandemic on household incomes through government aid such as social transfers, stimulus, and paycheck protection programs (World Bank 2021b), but low and middle-income countries generally had fewer financial resources and smaller government capacity to effectively offer such programs. Recorded remittances to low- and middle-income countries fell in 2020 by 1.6 percent compared to 2019. While this was a smaller decline than previously predicted, the distribution varied from increases in Latin America and the Caribbean (+6.5 percent) and South Asia (+5.2 percent) to decreases in sub-Saharan Africa (-12.5 percent), where Nigeria (-28 percent) experienced a particularly steep decline (World Bank 2021e). In the short run, decreased household income has resulted in both reduced food consumption and shifts in diet toward staples, especially among those with little or no savings (Ceballos, Hernandez, and Paz 2021; Laborde, Martin, and Vos 2021; Wang et al. 2021). A study conducted in central Myanmar found that even when households had access to informal borrowing and can sell assets, income loss due to COVID-19 still reduced nutritious food consumption of meat and fish (Ragasa et al. 2021). Income shocks have a significant effect on food security for people near the poverty line or already experiencing extreme poverty because they spend a greater percentage of their income on food and are sensitive to price changes. These shocks further exacerbate existing inequalities (Laborde, Martin, and Vos 2021; Swinnen and Vos 2021). Reduced and increasingly unequal levels of household income drove up poverty and food insecurity in 2020. These effects were primarily felt in low- and middle-income countries, where more people live just above the poverty line, have limited savings to cope with losses in household income, and where reduced government finances and capacity to facilitate direct cash-transfers limit the effects of economic growth on household income.

2.3.2 Immediate effects of COVID-19 on food availability and utilization

The COVID-19 pandemic is having limited effects on food availability and on production, and its impacts appear to be lower compared to previous pandemics (Laborde et al. 2020). In low-income countries the agricultural system is often labor-intensive. This poses some additional risks to agricultural production as a result of social distancing measures as well as exposure to COVID-19. (Laborde et al. 2020). But there is strong variation across countries in implementation of and adherence to social distancing measures. Preliminary evidence suggests that COVID-19 is having a stronger negative effect on labor-intensive supply chains and then on agricultural production, more strongly affecting low-income countries (Laborde et al. 2020). In Guatemala, restrictions on the movement of seasonal workers reduced both agricultural and nonagricultural income and remittance transfers in 2020 (Ceballos, Hernandez, and Paz 2021).

While low-income countries will be more affected by the pandemic, the impact across them varies greatly. For example, in Senegal, modern supply chains of large-scale fruit and vegetable companies were less affected than traditional supply chains dependent on small producers (Van Hoyweghen et al. 2021). School closures are limiting food availability but, more directly, food access for many children (Akseer, Kandru, et al. 2020; Laborde et al. 2020). And COVID-19 has spread rapidly in many food processing facilities, resulting in temporary closures and disruptions to food availability (Laborde et al. 2020). For example, in the U.S. the slaughter of beef declined by about 25 percent and hogs about 21 percent in April 2020, though the pace has stabilized since (Ramsey et al. 2021). Conversely, the global economic fallout, country-level export restrictions, and increased difficulties in importing food could trigger increases in domestic production in sub-Saharan Africa, resulting in long-term benefits to food availability (Laborde, Martin, and Vos 2021). In West Africa, trade flows were still affected by COVID-19 in April 2021, with some countries seeing higher demand for locally grown maize (FEWS NET 2021b).

A third avenue by which COVID-19 is affecting food availability is through disruptions in international trade. Such restrictions can limit the availability of food in food-import-dependent countries, increasing food prices and reducing access to food. Between March and July 2020, 21 countries imposed trade restrictions, representing about 4 percent of global food trade (International Trade Centre 2020). However, today almost all countries have lifted these restrictions. While international trade saw a downturn in 2020, agricultural trade was least affected of all sectors (WTO 2021). Trade restrictions and food stockpiling resulted in the vast majority of low-income countries experiencing moderate-to-severe increases in food prices in the second quarter of the year (World Food Programme 2020b, 48), highlighting the fact that the effects of changing patterns of trade may be primarily operating through economic food access. As a more recent example of this mechanism, in Cameroon, price rises in April 2021 in urban areas occurred because of import restrictions on rice (FEWS NET 2021b).

Physical restrictions imposed by lockdowns have reduced peoples' access to WATSAN infrastructure (Akseer, Kandru, et al. 2020). This poses a threat to the safe and clean processing of food and could further reduce utilization. However, the extent of the reduced access is unclear, and is likely to be temporary. In fact, some governments have invested in improving access to WATSAN systems as a means to combat the COVID-19 pandemic (Serrano and Torres 2020; World Bank 2020b). This could result in long-term benefits but depends on the durability of these investments. School closures are likely to result in permanent learning loss, with disproportionate impacts on girls. Education on healthy and safe nutrition is an important component of improving safe and healthy food utilization over the long term (Akseer, Kandru, et al. 2020). Further, studies have shown that parental education is an important driver of household nutrition, meaning the education setbacks due to COVID-19 may leave a long-term mark on future child stunting, wasting, undernourishment, and mortality (Gakidou et al. 2010; Vaivada et al. 2020). Thus, the impacts of education losses on food utilization and changes in access to WATSAN are likely to manifest over multi-year to decadal timeframes (Kaffenberger 2021; Verhagen et al. 2021).

COVID-19 is also shifting diets away from nutrient-dense foods such as vegetables, meat, and dairy toward staple foods such as maize, rice, and other grains (Laborde, Martin, and Vos 2021). As noted previously, there is empirical evidence in central Myanmar that income loss due to COVID-19 reduced nutritious food consumption of meat and fish (Ragasa et al. 2021). These effects are mostly indirect, occurring when increases in food prices and reductions in household income affect overall dietary quality.

2.3.3 Estimates of immediate effects of COVID-19 on food security

The short-term effects of COVID-19 on food security have been severe and operate primarily through impacts on food access, with smaller and mostly temporary effects on availability and utilization. Several nowcasting attempts have projected that COVID-19 will have driven down food security in 2020, with estimates ranging from 83 to 155 million additional food insecure people (Baquedano et al. 2020; FAO et al. 2020; WFP 2020; Laborde, Martin, and Vos 2021; Food Security Information Network and Global Network Against Food Crises 2021). Other nowcasting attempts have projected that by 2022 9.3 million children more under five will suffer from wasting, 2.6 million more children will suffer from stunting, and 168,000 more children will die (Osendarp et al. 2021). The impacts of COVID-19 do not operate in isolation but rather alongside food security threats, including conflict, political instability, and locust outbreaks. There is a risk that COVID-19 will fuel conflict and political instability (Moyer and Kaplan 2020), further darkening the outlook for food security in the next years. Therefore, the COVID-19 pandemic should be understood as a system-wide crisis, with impacts reaching far beyond the food system and across all aspects of economic, human, and environmental development. This becomes even more apparent when assessing the long-term impacts of COVID-19 on food security.

Table 1: Emerging evidence from the literature on the immediate and long-term effects of COVID-19 on food security.

Mechanism		Citations
Short-term Effects		
Food production, supply chains	Availability: Reduced labor, physical lockdowns, disrupted supply chains, and COVID-19 outbreaks in food processing facilities risked bringing down agricultural production. But government prioritization of food production has minimized this effect.	(Laborde et al. 2020; Laborde, Martin, and Vos 2021; Akseer, Kandru, et al. 2020)
Trade	Availability: International trade restrictions on food were put in place but have been mostly lifted. While trade has taken a hit, agricultural trade has been mostly unaffected.	(International Trade Centre 2020; WTO 2021)
Disrupted supply chains	Availability/Access: Physical lockdowns and international travel restrictions risked disrupting supply chains, but effective government measures on prioritization of food have limited these effects.	(International Trade Centre 2020; Laborde et al. 2020)
Food prices	Access: Food prices for many staple foods have increased because of COVID-19, trade restrictions, rising conflict, and the locust outbreak.	(World Food Programme 2020a; Abate, Brauw, and Hirvonen 2020; World Bank 2021a; Laborde, Martin, and Vos 2021)

Mechanism		Citations
Household income	Access: The economic contraction, reduced remittances, and physical lockdown have reduced household income. The consumption of food has been less affected because of reduced savings, but only for those who had the ability to save prior to the pandemic.	(Laborde, Martin, and Vos 2021; Abate, Brauw, and Hirvonen 2020)
Inequality	Access/Inequality: The short-term distributional effects of COVID-19 are largely unknown, with conflicting evidence on groups most strongly affected by household income and rural and urban differences in impact.	(Kharas and Hamel 2020; Mahler et al. 2021)
School closures	Access: School closures affect education, as well as access to food from school meals. Utilization: Limited access to school meals has the potential to limit dietary diversity and safe food processing for children in the poorer households.	(Akseer, Kandru, et al. 2020; Kaffenberger 2021; UNESCO 2020; 2021)
Dietary shifts	Utilization: Changing household income and food prices are projected to result in a shift away from meat, dairy, and vegetables toward staple crops. This is a coping mechanism for households.	(Laborde, Martin, and Vos 2021)
WATSAN	Utilization: Mixed evidence. Lockdowns reduced physical access to WATSAN, but the COVID-19 pandemic has also resulted in increased spending on WATSAN infrastructure.	(Akseer, Kandru, et al. 2020; Serrano and Torres 2020; The World Bank Group 2020)
Long-term Effects		
Economic growth	Availability: Reduced economic growth could reduce agricultural investment, especially for productivity-enhancing investments. Access: Reduced economic growth is coupled with reduced household income, driving up poverty and reducing access to food. Utilization: Reduced investment in education, WATSAN, and health systems.	(World Bank 2021c; Baquedano et al. 2020; FAO et al. 2020)
Inequality	Access/Utilization: Long-term unemployment and reduced education are expected to increase inequality because of COVID-19.	(World Bank 2021c; Fuentes and Moder 2021)
Education	Utilization: Temporary school closures tend to result in long-term learning losses, higher school dropouts, and long-term losses to human capital. Furthermore, reduced household income may lower education intake. Access: Lower education has long-term feedbacks to human capital, economic growth, and inequality.	(Kaffenberger 2021; World Bank 2021c)
Government debt	Government debt is rising, with anticipated disproportionate impacts on government finances in countries at high risk of debt sustainability. Availability: Reduced investments in agriculture.	(IMF 2021a; 2021b; IMF and World Bank 2021)

Mechanism		Citations
	Access/Inequality: Reduced spending on social welfare and education, with feedbacks to inequality. Utilization: Reduced government spending on education, health, and WATSAN, with potential feedbacks to education, economic growth, and inequality.	

2.3.4 Estimates of long-term effects of COVID-19 on food security

Understanding the effects of COVID-19 on long-term food security presents a challenge. Historically, data on food security is gathered through household surveys, but physical-distancing measures and lockdowns mean that much information on the effects of the pandemic on food security in 2020 are model-based estimates. Long-term projections of the impact of COVID-19 on food security have mostly looked out to 2030, modeling the impact through projected reductions in GDP, reflecting the consensus that economic accessibility will be the main pathway driving change (Baquedano et al. 2020; FAO et al. 2020; Laborde, Martin, and Vos 2021). For example, the U.S. Department of Agriculture (USDA) projects that by 2030 the number of people suffering from hunger worldwide will be 51 million greater than in a world without COVID-19 (Baquedano et al. 2020).

More broadly, long-term projections show that COVID-19 threatens achievement of social development goals, with a set of scenarios projecting global increases in extreme poverty (+0.8 to +2.5 percentage points) and undernourishment (+14 million to +45 million people) by 2030 and beyond, coupled with rises in gender inequality and reduced access to safe water and educational attainment (Hughes et al. 2021). Reports have also looked at heightened risks of increased child mortality over the next decade as a consequence of reduced access to WATSAN, higher food insecurity, and greater spread of communicable diseases, most notably diarrhea (D. Headey et al. 2020; Roberton et al. 2020; Verhagen et al. 2021; Osendarp et al. 2021). These studies show the potential widespread, long-term effects of COVID-19 on aspects of food security and, more generally, human development.

2.3.5 Long-term effects of COVID-19 on drivers of food security

The long-term effects of COVID-19 will likely be broad and encompass many systems critical for human development and food security. Most long-term effects are driven by broad changes in development trends that have forward impacts on food availability, access, and utilization. The links between these effects and food security may sometimes appear indirect, but these longer-term changes can be important determinants of the level of food security that can be projected in a post-COVID-19 world. For example, changes in food prices are important determinants of the impacts of the pandemic on food security today, but such COVID-induced changes may not pertain two decades hence. Similarly, today's lockdowns and school closures result in reduced physical access to food and school meals but are unlikely to pertain after restrictions have been lifted. But school closures also result in learning losses that can persist over time and in reduced education levels in the adult population over the next two decades, with forward effects on human development, economic growth, and indicators of food security. Many of these insights are based on emerging evidence and are shrouded in considerable uncertainty. Below, we describe the current understanding of how COVID-19 may shift long-term trends in food security.

COVID-19 and economic growth. The pandemic and the policy responses to curb the spread of the virus have resulted in a global, strong, but unequal economic downturn. The continued spread of the virus and the uneven distribution of vaccines will result in a global but uneven economic recovery (IMF 2021b) that risks further aggravating existing differences in socioeconomic and human development (Verhagen et al. 2021). Even as economies recover, there is concern that economic growth will be negatively impacted for as long as a decade. Several pathways will determine the long-term effects of the pandemic on economic growth (Fuentes and Moder 2021; World Bank 2021c).

The first pathway is through investment. A smaller economy and downward demand, driven by lower household incomes, makes some capital obsolete. This will be particularly relevant for certain sectors. For example, long-term reduced use of office spaces will reduce profits for leasing and cleaning companies. Together with a uncertain recovery and hesitancy to invest, this may result in a structural downturn of investment, especially among the most innovative investments (World Bank 2021c). More directly for food availability, the reduction in innovative investments can reduce growth in agricultural production in low- and middle-income countries.

Similarly, labor is another pathway through which COVID-19 affects long-term economic growth. The duration of the pandemic and associated rises in unemployment may increase the risk of long-term unemployment. Again, this effect is unlikely to be evenly distributed, primarily affecting certain sectors with limited availability to work from home (IMF 2021b). Another long-term labor effect is through education. Reductions in education today will result in a lower skilled labor force in the future, and if no counter actions are taken, further driving down economic growth (Kaffenberger 2021).

Together, reductions in investment in capital, in the labor force, and in capital and labor productivity could have prolonged downward effects on economic growth (Fuentes and Moder 2021; World Bank 2021c). Initial estimates, based on a comparison across previous pandemics, suggest a long-term reduction in labor, capital, and total factor productivity five years from now (Fuentes and Moder 2021). More generally, downturns in economic growth and GDP per capita are projected to force down the ability of households, governments, and businesses to invest in economic and human development out to 2040, impacting a wide array of socioeconomic indicators that jointly drive food security.

COVID-19 and government finances. Another pathway through which COVID-19 may have long-term scarring effects is through its impacts on government finances and debt. Government investments in health and measures to limit the economic fallout from the pandemic have resulted in significant increases in government indebtedness. At the global level, on average, fiscal deficits widened by 14.1 percent points of GDP in 2020 and an additional 2 percent was expected by 2021 (IMF 2021a; 2021b). This increase in government debt primarily falls on advanced economies (+17.9 percent in 2020), followed by emerging economies (+9.9 percent in 2020) and low-income countries (+5.2 percent) (IMF 2021a). While the strongest increases are observed in high-income countries, the risks of rising government debt to financial stability are expected to mainly fall on countries with high levels of government debt prior to the pandemic (IMF and World Bank 2021; IMF 2021a; 2021b).

There is much debate over the forward effects of rising government debt on economic growth, especially following the financial crisis of 2008 – 2009 (Caner, Grennes, and Koehler-Greib 2010; Herndon, Ash, and Pollin 2014; Reinhart and Rogoff 2010; 2011). Less contested is the notion that in the future, governments will need to realign their revenues and expenditures. This could come at a cost to government investment in health, education, WATSAN, agriculture, and the social welfare system, with long-term consequences for food utilization and food security in general.

COVID-19 and education. A third pathway through which the pandemic is likely to have impacts in the long term is education. Education will be simultaneously affected by reduced government spending and contracted household incomes, but also more directly through school closures. School closures are resulting in learning losses across the globe, with a disproportionate impact on girls (UNESCO 2020; World Bank 2020c). After restrictions cease, there is considerable risk the economic downturn will result in additional school dropouts, with some students not returning to school or failing to pursue, for example, tertiary education (UNESCO 2020). Even without this prolonged education downturn, losses in learning today can aggravate over time without policy responses, resulting in greater future learning losses (Kaffenberger 2021). Reduced educational attainment can drive down economic growth by reducing the skills of the labor force. It can result in gaps in parental education, resulting in child stunting, undernourishment, and mortality. And educational gaps foster societal inequality in the long run (Vaivada et al. 2020). Taken together, that means losses in education today will cause downturns in drivers of food security for the near to long term future.

COVID-19 and rising inequality. There is much uncertainty about the effect of COVID-19 on inequality. Initial household surveys show contrasting evidence. Rising food prices often negatively affect the poorest, who spend the greatest share of their limited incomes on food. But income shocks have also been shown to most impact middle-income households (World Bank 2020d). As a result, assessments of the impact of COVID-19 on poverty have either used a distribution neutral assumption or various assumptions about positive and negative changes in inequality (Kharas and Hamel 2020; World Data Lab 2020; Mahler et al. 2021).

In the long term, the downturn in economic growth, the reduction in educational attainment, reduced government spending and government benefits, growth in long-term unemployment, and disproportionate effects on females and youth tied to the pandemic are expected to further increase inequality (Fuentes and Moder 2021; World Bank 2021c). Although underlying data and analysis are contested, analyses show that previous pandemics have resulted in a rise in inequality, primarily driven by changes in economic growth and education (Furceri et al. 2020). Generally, persons more vulnerable to income shocks from COVID-19 work in agriculture, have low levels of formal education, and/or live in rural areas. Over the long-term, poorer households will therefore have less beneficial recovery trajectories compared to their more affluent counterparts (Hill and Narayan 2020; Swinnen 2020). Previous evidence, emerging data, and more conceptual understanding of coping mechanisms in the face of crises suggest that COVID-19 is likely to increase inequality over the long-term (Hill and Narayan 2020; Furceri et al. 2020; World Bank 2021c; Swinnen 2020) unless significant changes to government policies are made over the next year and maintained over the next decade.

In conclusion, we have identified a set of potential pathways through which COVID-19 can affect long-term food security. While economic growth and inequality primarily operate through a food accessibility pathway, additional secondary effects are expected for food availability and utilization. Thus, COVID-19 is affecting a wide array of underlying drivers of food security in the long run. Many immediate effects are short lived, with anticipated minimal effects on trade, or physical lockdowns restricting access to markets, school meals, and WATSAN. But without changes in policy, today's COVID-19 effects are expected, through multiple development pathways, to make marks on human and economic development for decades to come. In the next section, we build on these insights to construct scenarios describing alternative development pathways for food security with and without COVID-19.

3. Scenario framework for assessing the future of food security

3.1 Scenario framework

We use scenario analysis to explore the potential impact of COVID-19 on future food security, representing COVID-19 through a set of shock effects in 2020–2022, and focusing on those shocks likely to result in longer-term economic and human development downturns. We develop three scenarios: one counterfactual that represents a world without COVID-19, and two that represent a world in which COVID-19 has negative long-term consequences on socioeconomic and human development:

- The *No-COVID* scenario is a counterfactual scenario used to assess the effect of COVID-19 on food security. It represents a world in which COVID-19 did not occur and follows our best understanding of the development trajectory of individual countries prior to COVID-19.

- The *COVID-19 Current Path* scenario is a baseline scenario representing a world in which current COVID-19 trends continue, making use of emerging data series and other scenario forecasts on the impacts of COVID-19. In this scenario, vaccine rollout is effective against multiple strains of the virus, slowly limiting COVID-19 related deaths in 2021 and 2022 and the economic consequences of lockdowns. Economic growth follows most recent projections, with a strong bounce back in 2021 and 2022, and trade largely resumes its pre-pandemic patterns. However, there are still real and long-lasting effects on human development from school closures, increasing inequality, and rising government debt levels. The scenario assumes that governments take no actions to recover the loss in education from school closures or the rise in inequality and government debt levels. The long-term effects are largely shaped by the reduction in economic size and household income and primarily develop through reduced economic accessibility to food.

- The *COVID-19 Unequal Paths* scenario is a downward scenario representing a world in which the struggle with COVID-19 continues, and long-lasting scarring effects primarily fall on the most vulnerable countries. In this scenario, vaccine rollout is slow outside of high-income countries, resulting in continued deaths and the emergence of virus variants in many low-income and emerging economies, with downward projections for economic growth and recovery from 2020[10] to 2022. Inequality rises further, especially in countries with large informal economies and lower government capacity to manage welfare payments. Additional school closures result

[10] Growth rates for 2020 are increasingly being based on data, rather than estimated growth projections. Still, we opted for changing the growth rates given that still much is unknown about effects of the pandemic in 2020 and growth rates vary considerably between different agencies, even for 2020.

in larger permanent downturns in education quality and increasing numbers of dropouts, especially among females and regarding tertiary education. Government debt reaches unsustainable levels in countries with already elevated debt, resulting in negative effects on economic growth and increased pressure on government spending on education, health, WASH, and welfare payments. This scenario sketches a world in which existing vulnerabilities are further aggravated by the pandemic, resulting in additional long-lasting effects on economic and human development. The negative long-term effects of COVID-19 multiply existing country-level vulnerabilities and operate through effects on economic accessibility, food utilization, and general patterns of economic and human development.

Methodological insight

We develop two COVID-19 scenarios tracking the effects of the pandemic on economic growth, rising inequality, government finances, and education loss. We also develop one No-COVID-19 counterfactual scenario.

The above scenarios aim to sketch contrasting and diverging worlds with different development trajectories and consequences for drivers and indicators of food security at national, regional, and global levels. However, these scenarios are not capable of capturing the full range of uncertainty associated with the direct and long-term impacts of COVID-19. Nor do they sketch worlds in which policymakers actively try to steer development through implementation of policies aimed at additional recovery. To capture some of the uncertainty surrounding these estimates, we provide additional varying scenario assumptions on economic growth and inequality in Appendix D. To assess the uncertainty in growth projections across agencies, we ran a scenario with World Bank growth rates (World Bank 2021b). To assess the uncertainty in the additional downward revision, we varied the -1.5 percent assumption. These additional scenario assumptions serve a dual purpose: 1) to identify the range of uncertainties surrounding the proposed estimates, and 2) to identify critical assumptions, i.e., drivers that have a strong effect on long-term projections of food security.

3.2 The International Futures model

We operationalize this scenario analysis in the International Futures model (IFs). The International Futures model is a modeling platform designed for projections of long-term development patterns across areas of human, socioeconomic, and biophysical systems. It falls within a broader set of integrated system models, tools designed to answer multidimensional integrated questions on long-term human and environmental development. IFs represents the world as a set of interconnected systems across agriculture, demography, economics, education, governance, health, infrastructure, trade, and environmental change. It provides projections across all these domains, in integration, for 186[11] countries, going out to 2100. IFs has been widely used in policy-science interface to inform strategic thinking across a host of development topics, with a recent specific focus on questions about COVID-19 and human development, as well as in the academic literature. The model is open source, and documentation can be found online.[12] For a further description of the model and its core components, see Appendix C.

[11] IFs provides projections for 186 countries. However, for the analysis presented here we exclude Libya, given GDP growth rates of -59.7 percent in 2020 and +131.0 percent in 2021, according to IMF.

[12] https://pardee.du.edu/wiki/Main_Page

The IFs model represents various indicators of food security at the country level. It projects long-term forecasts of extreme poverty, prevalence and number of people undernourished, and child stunting. The IFs model is the only modeling platform capable of projecting food availability, food accessibility, and food utilization endogenously. Food availability is broken down into crops, meat, and fish and is driven by changes in domestic agricultural production through land use and production intensity coupled with international trade of food. In general, food availability aims to meet food demand and is limited by biophysical constraints on land availability and intensity of production, both domestically and internationally. Food accessibility is a combination of food availability with access to food. Access to food is determined by demand for food, driven by changes in economic affluence and population size. In addition, economic accessibility is driven by changes in food prices, coupled with an indicator on inequality to food access. Last, the IFs model represents food utilization for indicators of child malnourishment. Food utilization is driven by aspects related to a deficient household environment. These indicators include access to safe water and sanitation and levels of maternal education. For a further description of food security in the IFs model and the specific formulations used for the forecasts, see Appendix C.

Table 2: Scenario assumptions informing the *No-COVID*, *COVID-19 Current Path*, and *COVID-19 Unequal Paths* scenarios, including data sources to inform the scenario assumptions.

	No-COVID	***COVID-19 Current Path***	***COVID-19 Unequal Paths***	**Data sources**
GDP growth	Country-level GDP for 2020–2022 follows pre-COVID GDP growth rates. Beyond 2022, the GDP growth follows the IFs endogenous forecast.	Country-level GDP growth for 2020–2022 comes from IMF GDP growth forecasts.[13]	Country-level GDP growth in 2020, 2021, and 2022 from the *Current Path* is lowered by 1.5 percent across all countries.	World Economic Outlook (WEO) GDP growth rates for 2020–022 from IMF (IMF 2021b). Beyond 2022, the GDP growth follows the IFs endogenous forecast.[14]
Inequality	Distribution of income and of calories at the country level is kept constant at the 2019 level.	COVID-19 increases inequality in distribution of income and distribution of calories, across all countries by +1 percent. The increase is assumed constant over time.	COVID-19 increases inequality, with a disproportionate impact on countries with low government capacity. The distribution in income and in calories is unchanged in countries with high government capacity and further increases in countries with medium (+1 percent) and low capacity (+2 percent).	Own projections on government capacity from the IFs model, internal calculations of coefficient of variation (caloric distribution) and data from World Bank on Gini (income distribution) (World Bank 2020a).
Government debt	Government debt follows a pre-COVID trajectory and no change to revenues and expenditures associated with COVID-19.	COVID-19 increases government debt according to income level group. The model endogenously calculates effects on economic growth and government expenditures.	COVID-19 increases government debt according to income level group. In countries with high risk of debt unsustainability, this results in an additional reduction in government expenditures of 5 percent for the next decade across all spending categories.	(IMF and World Bank 2021; IMF 2021a).
Education	Education follows a pre-COVID trajectory, with no change to quality or	COVID-19 increases dropouts, following estimates by UNESCO specified for income level group,	Dropouts are multiplied by a group-dependent multiplier of 1, 1.5, and 2, depending on the extent of school	(Azevedo et al. 2020; UNESCO 2020; 2021).

[13] Pre-COVID estimates on GDP growth stem from 2019, whereas COVID-19 estimates are from 2021. This sometimes results in countries having higher GDP growth in 2020 with COVID-19. This is unlikely to stem from a positive economic growth effect, but rather reflects more recent information regarding economic conditions. In other words, we still assume those countries to have higher growth rates without COVID-19. We adjusted GDP growth rates for a small subset of countries in 2020–2022 such that *No-COVID* scenario growth rates are better or equal than COVID-19 growth rates for all countries.

[14] Appendix D contains a sensitivity analysis in which: 1) GDP growth rates are based on World Bank projections, and 2) we adjust growth rate and inequality assumptions to assess the sensitivity of the results to these drivers.

	No-COVID	*COVID-19 Current Path*	*COVID-19 Unequal Paths*	Data sources
	dropouts from COVID-19 school closures.	sex, and level of education. Education quality is reduced, following the baseline scenario estimates by the World Bank, per income group.	closures. Education quality follows the worst-case scenario across all groups and is multiplied by the same group-dependent factor.	
Child malnourishment	Child malnourishment follows a pre-COVID trajectory.	Child malnourishment follows the endogenous IFs forecast, without any additional COVID-19 effects.	We account for additional short-term effects of COVID-19 on child undernourishment by raising both child wasting and child undernourishment by 14 percent in low- and middle-income countries in 2020 and allowing these rises to fully feed forward to child stunting.	(Headey et al. 2020; Headey and Ruel 2020; UNICEF, WHO, and World Bank Group 2021).
Additional COVID-19 shock	No additional shock.	Rise in 2020 mortality per country, and an increased trade elasticity to GDP in 2020 and 2021.	Like *Current Path*, rise in 2020 mortality per country and an increased trade elasticity to GDP in 2020 and 2021.	(IHME 2020; WTO 2021).

3.3 Scenario assumptions and indicators

The scenario narratives and specific assumptions in this report are informed by previous studies, emerging data, insights from the literature, and an expert consultation. We organized a series of six expert meetings with representatives from World Bank, International Food Policy Research Institute, USAID, and universities (for a list of participants, see Appendix A). The meetings were organized around scenario assumptions on COVID-19 effects on economic growth, inequality, education, and government finances.

Table 2 provides an overview of scenario assumptions and sources of data for the *No-COVID*, *Current Path*, and *Unequal Paths* scenarios. We compare the three scenarios for indicators of extreme poverty, undernourishment, and child stunting at the regional and global levels, out to 2040. In addition, we quantify underlying drivers of food security, and changes therein, over the same period to assess the pathways through which COVID-19 affects food security. GDP growth rates for 2020 to 2022 across the different scenarios were taken from the April 2021 IMF WEO (IMF 2021b). In the *Unequal Paths* scenario, we further decrease GDP growth by -1.5 percent in all three years. This is an assumption, and we test the sensitivity of the results to alternative growth adjustments in Appendix D. We opted for -1.5 percent because the global mean difference in GDP growth projections from World Bank and IMF are about 1.5 percent in 2020 (World Bank 2021b; IMF 2021b) and differences in growth rates from IMF from April 2020 to April 2021 also vary by about 1.6 percent (IMF 2020; 2021b). Thus, -1.5 percent seems a reasonable downward adjustment. Although 2020 is in the past, we adjust GDP growth rates for this year as well, since there are still considerable differences between 2020 GDP growth rate estimates from various international organizations. For education, the scenario interventions are implemented from primary to tertiary levels. While dropouts are specific to education level, effects on education quality and the multiplicative effects of school closures are not, since no projections or data were available for this. In both COVID-19 scenarios, we also implemented an additional shock-effect of the pandemic to capture some possible short-term consequences that are hard to fully represent in a model designed for long-term projections. We represent the same set of shocks across all scenarios. They include additional imposed mortality in 2020 based on IHME numbers and a trade elasticity to GDP. However, neither of these assumptions affect long-term forecasts in the IFs model. In addition, in the *Unequal Paths* scenario we implement an additional shock to malnourished children and child wasting, to capture some of the uncertainty concerning immediate effects on child malnourishment and stunting. These scenarios capture a wide set of potential effects of COVID-19, with a focus on interventions with longer-term effects on food security.

We quantify the effects of COVID-19 on outcome indicators (Section 4) and on underlying drivers of food access, availability, and utilization at both the regional and global levels. Some results are also presented for sets of countries. As introduced earlier, the regions discussed in this report are Canada and the U.S., Latin America and Caribbean, Europe, Commonwealth of Independent States, Middle East and North Africa, sub-Saharan Africa, Southern Asia (with results strongly driven by India), and Eastern Asia (with results strongly driven by China), Southeast Asia, and Oceania. For descriptions, see Appendix B.

4. Results: Quantifying extreme poverty, undernourishment, and child stunting in 2040, and the effect of COVID-19 thereon

Purpose: This section quantifies the three outcome indicators for food security in 2020 and out to 2040, with and without COVID-19. For each indicator, we first discuss the baseline trend out to 2040 using the *Current Path* scenario, which includes impacts of COVID-19. This helps the reader understand general projected trends across development indicators. Next, we quantify the effect of COVID-19 in 2020 and 2040 on these three indicators. The analysis provides insights on the effects of COVID-19 on extreme poverty, undernourishment, and child stunting, relative to overall trends in development. Results are presented for regions and the world.

4.1 COVID-19 and extreme poverty

4.1.1 Trends in global extreme poverty to 2040 with COVID-19

Poverty is driven most directly by changes in household income and economic growth and the distribution of household income within a country. COVID-19 is affecting poverty by changing both economic growth and the distribution of household income. While household savings can offset income shocks, levels of such savings tend to be small in low-income economies, especially for poor to near-poor households. To understand the effects of COVID-19 on extreme poverty, we first describe overall trends in these three indicators in the *Current Path* scenario, which already includes effects of COVID-19. We estimate extreme poverty in the *Current Path* scenario to have risen in 2020[15] to 10.1 percent, from 8.9 percent in 2019. This is the first rise in global extreme poverty since 1998.

Prevalence of extreme poverty

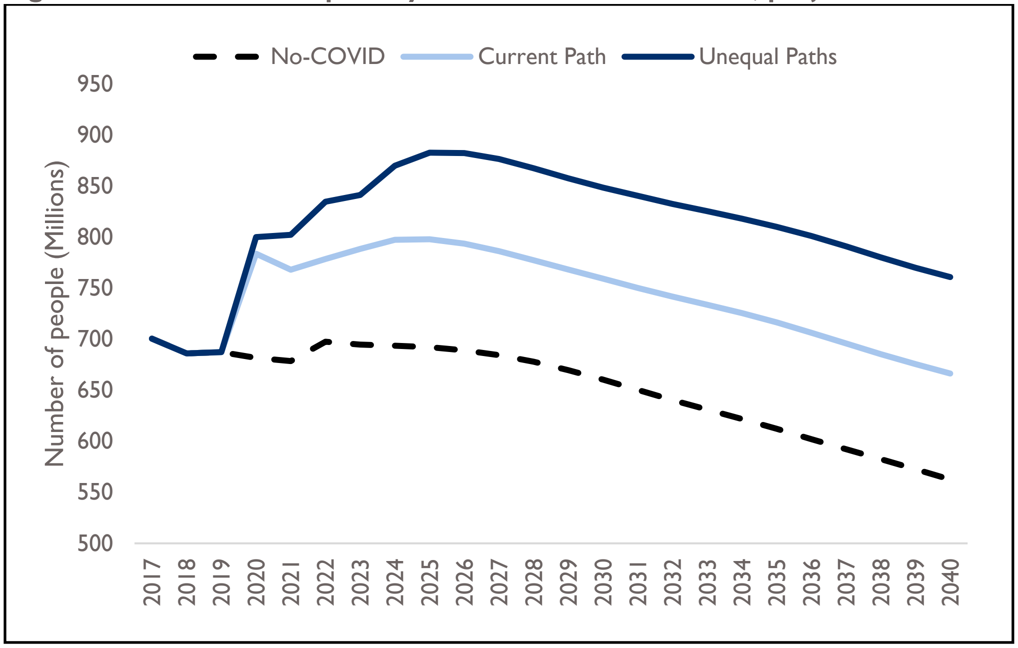
Even considering the impacts of COVID-19, gradual progress is expected in lowering extreme poverty worldwide over the next two decades. In the *Current Path* scenario, extreme poverty is projected to decrease from 10.1 percent in 2020 to 7.2 percent in 2040.

According to this analysis, the world is still set to make gradual progress in eradicating poverty over the next two decades (Figure 4). The prevalence of extreme poverty drops from 10.1 percent in 2020 to 7.2 percent in 2040. Progress on eradicating absolute numbers of extreme poverty is much more challenging given high population growth, especially in areas with already high levels of extreme poverty

[15] When this analysis was performed, no data was available for 2020 that fully captured the COVID-19 effect on global extreme poverty, undernourishment, or child stunting. Data collection for these indicators strongly depends on household surveys, which have been largely suspended by COVID-19. This means that for 2020 we strongly rely on projections to understand the effects of COVID-19 on human well-being indicators at the global level. As such we project these indicators but use 2020 estimates.

today. Extreme poverty drops from 783.6 million in 2020 to 666.3 million in 2040, only slightly lower than the 687 million extremely poor people in 2019.

Figure 4: Global extreme poverty across the three scenarios, projected out to 2040.



Note: Extreme poverty is measured as the number of people living with less than $1.90 per day. Projections start in 2017.
Source: Authors' calculations.

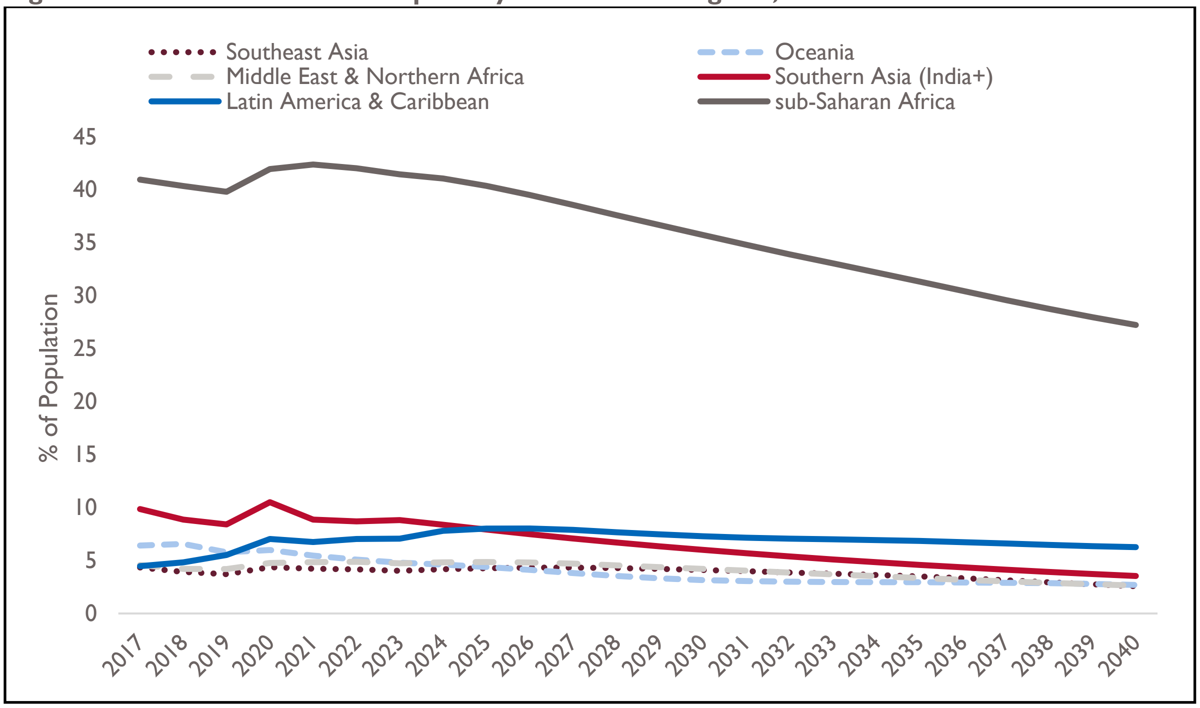
Extreme poverty is unequally distributed across world regions. Of the global population living in poverty in 2020, 59.7 percent were in sub-Saharan Africa and 25.9 percent were in Southern Asia. By 2040, the distribution of extreme poverty is projected to be even more skewed toward sub-Saharan Africa, with 74.1 percent of all people in extreme poverty living there, and 11.8 percent in Southern Asia. Across all world regions, the prevalence of poverty is projected to drop, from 41.9 percent in sub-Saharan Africa in 2020 to 27.2 percent in 2040, and from 10.5 percent in 2020 in Southern Asia to 3.5 percent over the same period (Figure 5). But while the prevalence of poverty is projected to drop in sub-Saharan Africa, the absolute number of people in extreme poverty in the region is projected to increase due to strong population growth, going from 467.5 million in 2020 to 493.7 million in 2040. Only 25 out of the 49 countries in sub-Saharan Africa are projected to have lower absolute numbers of people living in poverty in 2040 compared to 2020. In other regions poverty is projected to drop both as percentage of the population and in absolute number of people. In Southern Asia progress is strongly driven by the reduction of poverty in India.

Geographic distribution of extreme poverty

Extreme poverty today is primarily concentrated in Southern Asia and Sub-Saharan Africa. By 2040 it is projected that 74.1 percent of all people in extreme poverty will live in Sub-Saharan Africa.

Other regions had much smaller shares of the global population living in extreme poverty in 2020, with the Middle East and North Africa (4.8 percent), Oceania (6.0 percent), Southeast Asia (4.4 percent), and Latin America and the Caribbean (7.0 percent) all above 3 percent (Figure 5). That in itself, of course, does not mean that extreme poverty is necessarily lower across all these countries. For example, Papua New Guinea (with 22.4 percent of the population in extreme poverty in 2020) makes up 80.3 percent of all extreme poverty in the Oceania region, and Yemen (with 53.1 percent of the population in extreme poverty in 2020) accounts for 61.5 percent of all extreme poverty in the Middle East and North Africa region. In the top 15 countries with the highest levels of poverty in 2020, only Yemen (rank 12) and Venezuela (rank 11) are countries not in sub-Saharan Africa or Southern Asia. Thus, global extreme poverty in 2020—and even more so out to 2040—is predominantly oriented toward sub-Saharan Africa and to a lesser extent Southern Asia.

Figure 5: Prevalence of extreme poverty across world regions, in the *Current Path* scenario.



Note: Projections start in 2017, and 2015–2016 are data points. We excluded regions with less than 1 percent of the population in poverty (Canada and U.S., Commonwealth of Independent States, Eastern Asia, Europe).
Source: Authors' calculations.

4.1.2 Quantifying the effect of COVID-19 on extreme poverty in 2020 and 2040

We study the effects of COVID-19 on extreme poverty by quantifying the difference between a *No-COVID* counterfactual and two COVID-19 scenarios (*Current Path* and *Unequal Paths*). We do not provide a single point estimate but rather quantify the range of the two COVID-19 effects on extreme poverty out to 2040. COVID-19 results in a 6- to 12-year setback in poverty eradication at the global level by 2040. This means that the poverty prevalence in 2040 in the *Current Path* scenario would have been reached six years earlier in the *No-COVID* scenario (2034), and the *No-COVID* scenario reaches the level of poverty in 2040 in the *Unequal Paths* scenario 12 years earlier (2028). Overall, COVID-19 slows down progress on eradicating extreme poverty, without reversing the global trend of slow and gradual progress. The effects of COVID-19, without changes in policy, are persistent out to 2040, with higher poverty numbers compared to a *No-COVID* world.

COVID-19 increased global extreme poverty in 2020 by 14.9 percent to 17.3 percent, or an estimated 101.9 to 118.3 million, depending on the COVID-19 scenario (Figure 4). This estimate lies between poverty estimates produced by others, with analysis by Laborde, Martin, and Vos (2021) projecting a rise in poverty of 150 million, an analysis by Sumner, Hoy, and Ortiz-Juarez (2020) ranging between 84.9 million to 419 million, an analysis by World Bank projecting a rise of 97 million (Mahler et al. 2021), and at the lower end, estimates projecting increases between 39 million and 60 million (Bill & Melinda Gates Foundation and IHME 2020; Kharas and Hamel 2020). While most of these studies use GDP growth rates to project poverty values, a one-to-one comparison across these estimates is challenging because GDP growth forecasts have changed substantially over the last year,[16] and substantial differences exist between studies that do or do not account for changes in inequality because of COVID-19.

Extreme poverty in 2020 and in 2040

COVID-19 is estimated to have increased extreme poverty in 2020 by 101.9 (*Current path)* to 118.3 (*Unequal path*) million, relative to a No-COVID scenario. This is the first rise in global extreme poverty in this century.

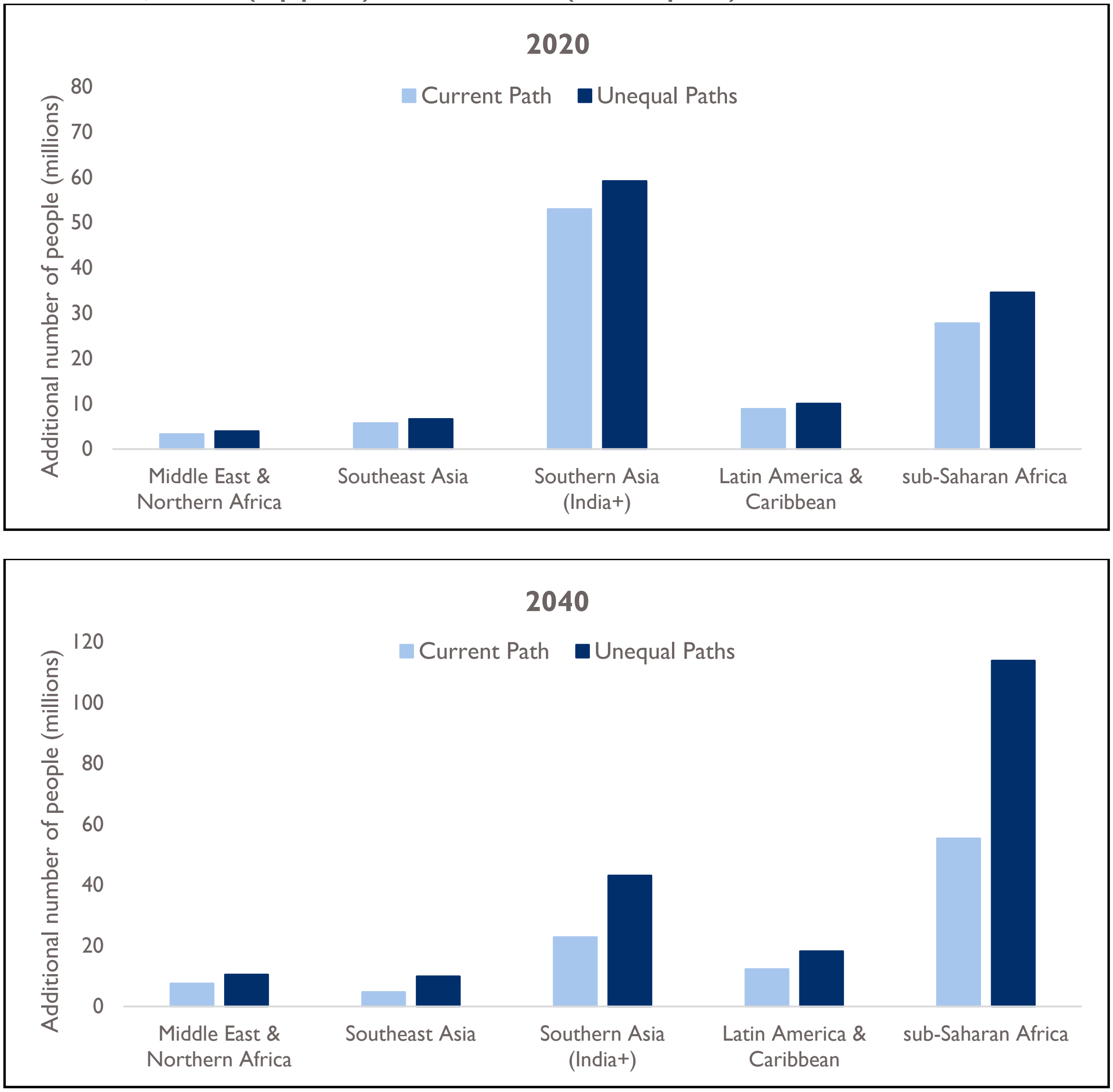
In 2040 our projection shows COVID-19 slows down the progress on eradicating extreme poverty, resulting in a 6 to 12-year setback in lowering extreme poverty relative to a world without COVID-19.

By 2040, COVID-19 is projected to increase global extreme poverty by 18.5 percent to 35.2 percent, or an estimated 103.9 to 198.3 million people (Figure 4) as compared to a no-COVID scenario. Among other things, the 94.4 million difference between the two COVID-19 scenarios shows not only the great uncertainty associated with COVID-19 effects in general, but also the risk that additional long-term scarring effects of the COVID-19 pandemic could carry for increasing extreme poverty. The 94.4 million difference between the two COVID scenarios is roughly the size of the number of people in extreme poverty in Nigeria today (91.2 million). Based on previous economic shocks and pandemics, many scholars fear COVID-19 could have longer-term negative effects across systems of economic growth, education, inequality, and government finances, highlighting the need to implement policies today that can minimize these longer-term risks.

The increase in poverty from COVID-19, relative to a *No-COVID* scenario, primarily falls on sub-Saharan Africa and Southern Asia. In sub-Saharan Africa, estimates of the growth in poverty from COVID-19 vary from 27.8 to 34.6 million in 2020 and rise to 55.3 to 113.8 million by 2040 (Figure 6). For Southern Asia, rises in poverty from COVID-19 have larger immediate effects in 2020 (53.0 to 59.2 million) but smaller longer-term effects (22.8 to 43.1 million). These differences in regional dynamics are largely determined by differences in population growth, since both world regions see a net decrease in the prevalence of poverty from 2020 to 2040 across all scenarios. These projections suggest that not only will COVID-19 increase poverty out to 2040, relative to a *No-COVID* scenario, but more importantly, these increases in poverty will primarily occur in already-vulnerable regions.

[16] To assess the importance of GDP assumptions and distributional effects, we provide a sensitivity analysis in Appendix D.

Figure 6: Additional people in extreme poverty, between a *No-COVID* scenario and the two COVID-19 scenarios, in 2020 (top panel) and out to 2040 (bottom panel).



Note: The rise in poverty is depicted for five world regions. We exclude regions with less than one million additional people in poverty (Canada and U.S.; Eastern Asia; Commonwealth of Independent States, Europe, and Oceania. See Appendix B for all world regions).

Source: Authors' calculations.

4.2 COVID-19 and undernourishment

4.2.1 Trends in undernourishment to 2040 with COVID-19

The number of undernourished people and the PoU in the population are driven by changes in calories per capita at the country level, and the distribution of calories across the population. These are the result of changes in food availability through agricultural production and trade, food access through economic changes, demand-side effects, and to a lesser extent by food utilization related to dietary shifts from vegetables and meats to staple crops. All these systems change over time, but COVID-19 is primarily affecting food accessibility and the distribution of calories within populations, with smaller anticipated effects on overall food availability and food utilization. Before we assess the effect of COVID-19 on undernourishment, we focus on general trends in undernourishment over time from the *Current Path* scenario. In 2020 in the *Current Path* scenario, undernourishment is affecting 11.3 percent of the global population, up from a level of 10.9 percent in 2019.

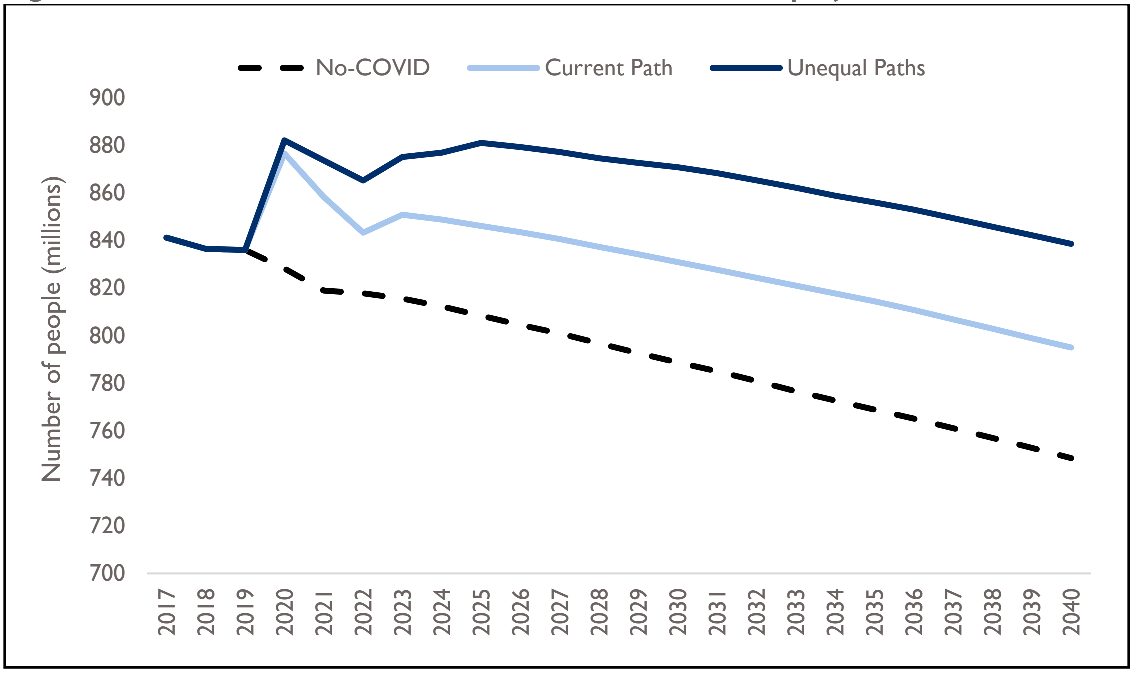
Undernourishment

Despite the effects of COVID-19, the world is still set to make gradual progress in lowering the prevalence of undernourishment by 2040.

The PoU is projected to gradually drop over the next two decades, largely driven by more affluent populations with higher demand for calories per capita, in scenarios with and without COVID-19. The prevalence of undernourishment drops from 11.3 percent in 2020 to 8.6 percent in 2040, whereas absolute numbers drop from 876.6 million in 2020 to 795.0 million by 2040 (Figure 7). Rises in GDP per capita result in higher food demand, with calories per capita increasing from an average of 2,100 per capita per day in 2020 to 3,100 calories per day in 2040. The rise in per capita demand coupled with population growth means that the world is facing increased challenges to feed a rising population, but the global agricultural system is projected to be able to keep up with global food demand. The projected improvements in undernourishment are primarily driven by rising household income resulting in increased calories per capita.

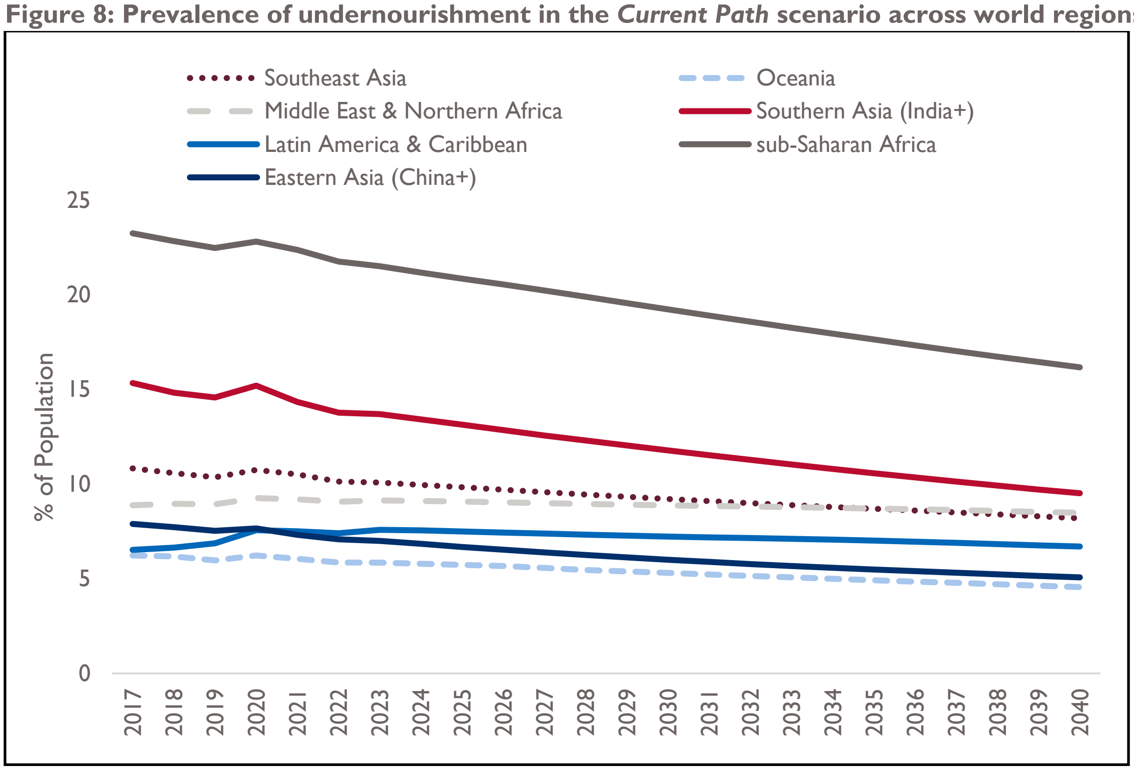
Undernourishment has been on the rise in the last few years. This is largely attributed to rising levels of conflict (FAO et al. 2020), but it is unclear whether this trend is likely to continue in the future. Two recent reports providing longer-term projections on food security follow the same trajectory, with an initial increase in undernourishment in 2020 and 2021 followed by a gradual decline to 2030. The scenarios presented here account for some continued effects of conflict and climate change on food security, but do not incorporate major disruptive events from climate change, conflict, political instability, or future pandemics on food security.

Figure 7: Global undernourishment across the three scenarios, projected out to 2040.



Note: Projections start in 2017.
Source: Authors' calculations.

Figure 8: Prevalence of undernourishment in the *Current Path* scenario across world regions.



Note: We excluded regions with a prevalence of undernourishment under 5 percent (Canada and U.S.; Europe, Commonwealth of Independent States). Projections start in 2017.
Source: Authors' calculations.

The distribution of undernourishment follows a similar pattern as that of extreme poverty but is less concentrated in sub-Saharan Africa and Southern Asia (Figure 8). In 2020, the largest share of the undernourished population was in sub-Saharan Africa (22.8 percent), followed by Southern Asia (15.2 percent). The PoU is lower in other regions, but still above five percent in Eastern Asia (7.6 percent), the Middle East and North Africa (9.3 percent), Southeast Asia (10.8 percent), and Latin America and the Caribbean (7.6 percent).

As 2040 approaches, progress is projected in reducing undernourishment across most world regions, with the largest decline in sub-Saharan Africa and Southern Asia. However, coupled with population growth, there are strongly opposing trends across regions in the number of undernourished people, with strong declines in Eastern Asia (-42.4 million) and Southern Asia (-70.2 million), driven respectively by China and India and, to a lesser extent, Bangladesh. The opposite is true for the Middle East and North Africa (+7.9 million), sub-Saharan Africa (+40.9 million), and Latin America (+1.2 million), where the number of undernourished people is projected to be greater in 2040 relative to 2020. By 2040, out of all undernourished people, 38.5 percent are projected to live in sub-Saharan Africa, and 27.8 percent in Southern Asia. At the country level, the largest increases in the *Current Path* scenario in undernourishment occur respectively in Tanzania and Nigeria in sub-Saharan Africa, and Yemen, Egypt, and Iraq in the Middle East and North Africa region. In Latin America, the rise in undernourishment is almost entirely driven by Venezuela, which in recent years has seen a spike in undernourishment from economic, political, and food crises.[17]

4.2.2 Quantifying the effect of COVID-19 on undernourishment in 2020 and 2040

We study the effect of COVID-19 on undernourishment by comparing a *No-COVID* scenario to two COVID-19 scenarios. Within these scenarios, COVID-19 has direct effects on undernourishment, driven by lower economic growth and changes in the distribution of calories across populations. The primary pathway causing change in undernourishment is through food access and inequality. In the longer-term, economic growth reductions further increase undernourishment. For instance, decreased agricultural investments reduce crop yields and the amount of land under cultivation. As government finances decrease, so does investment in access to WATSAN and education (see Section 5 for more detail on the underlying drivers).

By 2040, COVID-19 results in a 4- to 8-year setback in the PoU. In other words, the levels of undernourishment reached in 2040 in the *Current Path* scenario would have been reached four years earlier without COVID-19. This setback is slightly less pronounced than the setback to poverty, as some households can lessen economic impacts by spending larger shares of their income on food and/or by shifting diets away from diverse and nutrient-rich foods, such meat and vegetables, toward staple foods in order to maintain a certain level of calorie consumption. Of course, consumption shifts as a coping mechanism are less of an option for already poor to near-poor households across the world, which allocated a large share of their consumption to food prior to COVID-19. In addition, these types of shifts in dietary patterns are likely to have negative impacts on affected households (e.g., reduced protein and micronutrient intake).

---

[17] Of course, it is possible that the economic, political, and food crisis in Venezuela will be resolved in the near future. In 2020, the country's GDP growth rate was projected at -30 percent. The IFs model projects negative growth until 2027, and afterward, it projects positive growth, albeit at low rates.

In 2020, we estimate a rise of 5.8 percent to 6.5 percent in global undernourishment, equivalent to an increase of 48.4 to 53.9 million people, relative to a *No-COVID* scenario (Figure 7). In the *Current Path* scenario, the effects of COVID-19 in 2020 are followed by gradual declines in undernourishment in the following years because of economic recovery. The *Unequal Paths* scenario describes a world with both short-to-medium-term effects, with gradual declines starting from 2025 onward. Thus by 2025, the effects of COVID-19 on undernourishment are projected to diverge more strongly than in 2020 across the scenarios, with increases ranging between 37.7 to 72.7 million, relative to the *No-COVID* scenario.

Undernourishment in 2020

In 2020, our analysis shows COVID-19 resulted in a rise in undernourishment of 48.4 to 53.9 million globally, relative to a No-COVID scenario.

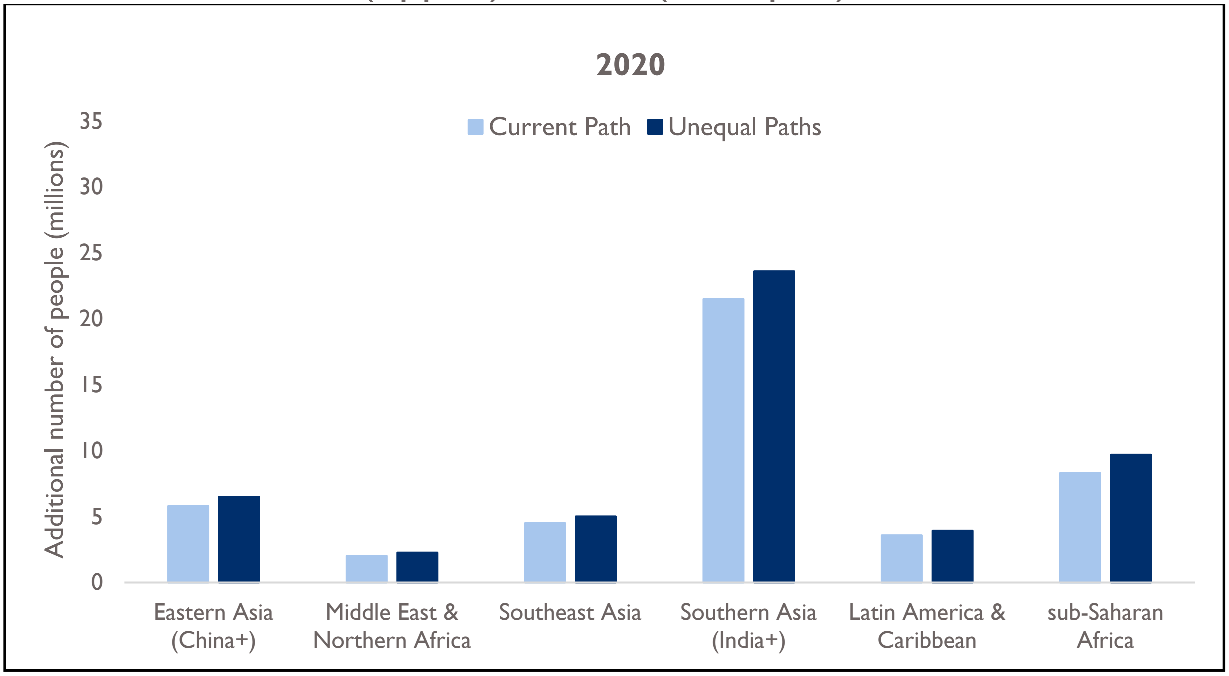
These estimates are at the lower end of other projections of the impact of COVID-19 on undernourishment. The USDA estimates an additional 83.5 million people would suffer from undernourishment in 2020 and the FAO estimated 83 to 132 million additional people would live in hunger the same year. This range of estimates shows the uncertainty associated with undernourishment in 2020 because of COVID-19. What we do know is that much uncertainty is associated with GDP and distributional effects from COVID-19. We provide a sensitivity analysis in Appendix D.

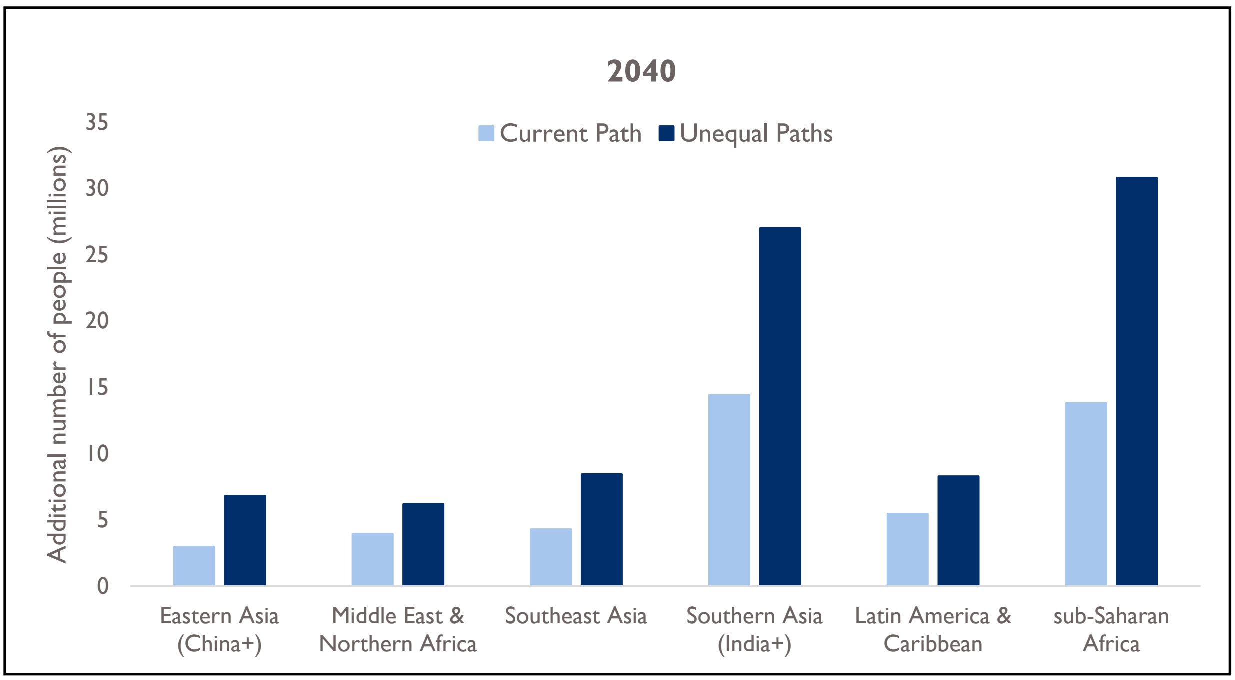
We project undernourishment to increase globally because of the pandemic by 6.2 percent to 12 percent by 2040, equivalent to a rise of 46.5 million to 90.0 million people, relative to a *No-COVID* scenario (Figure 9). The difference between the two COVID-19 scenarios suggests a potential doubling of the effect on undernourishment by 2040, assuming additional longer-term downturns and no policy changes to boost inclusive economic growth and human development beyond the pandemic. The difference of 43.5 million between the two COVID-19 scenarios is equivalent to the total number of people undernourished today in Pakistan (also 43.5 million, which in 2020 ranked third highest across all countries in undernourishment), showing the extent of the potential additional effect from slowed economic recovery, continued education losses, constrained government finances, and rising levels of inequality, as depicted in the *Unequal Paths* scenario. In 2019, 835.9 million people suffered from undernourishment, a level that would only be reached in 2041 in the *Unequal Paths*, scenario. This suggests that this downside scenario indicates higher levels of undernourishment globally for the next two decades, relative to 2019.

Undernourishment in 2040

By 2040 our projection shows COVID-19 will result in an increase in undernourishment of 6.2 percent to 12 percent, relative to a No-COVID scenario. The more pessimistic *Unequal Paths* COVID-19 scenario thus roughly doubles the effect on undernourishment.

Figure 9: Additional number of undernourished people between a *No-COVID* scenario and the two COVID-19 scenarios in 2020 (top panel) and in 2040 (bottom panel).





Note: The rise in undernourishment is depicted for six world regions, excluding those with fewer than two million additional undernourished people (Canada and U.S., Commonwealth of Independent States, Europe, and Oceania).
Source: Authors' calculations.

Geographic distribution of undernourishment

COVID-19 is projected to increase undernourishment primarily in the two regions already struggling with food insecurity, from 13.8 to 30.8 million in sub-Saharan Africa and from 14.4 to 27.0 million in Southern Asia between 2020 and in 2040, relative to a No-COVID scenario.

COVID-19 increases undernourishment primarily in the two regions already struggling with food insecurity (Figure 9). In 2020, the undernourished population is estimated to have increased by 8.3 to 9.7 million in sub-Saharan Africa and 21.5 to 23.6 million in Southern Asia. Importantly, the estimated increase in Southern Asia is based on data prior to the 2021 outbreak of COVID-19 in India and other countries in Southern Asia, and the associated human and socioeconomic losses[18] By 2040, these regions are projected to continue to experience the largest impact of COVID-19 on undernourishment, with increases of 13.8 to 30.8 million in sub-Saharan Africa and 14.4 to 27.0 million in Southern Asia.

The increase in either sub-Saharan Africa or Southern Asia in 2040 is larger than the combined growth of undernourishment in Southeast Asia, Latin America and the Caribbean, and the Middle East and North Africa. We thus project that COVID-19 will worsen undernourishment outlooks relative to a *No-COVID* scenario, with a disproportionate effect in regions with the highest burden of undernourishment.

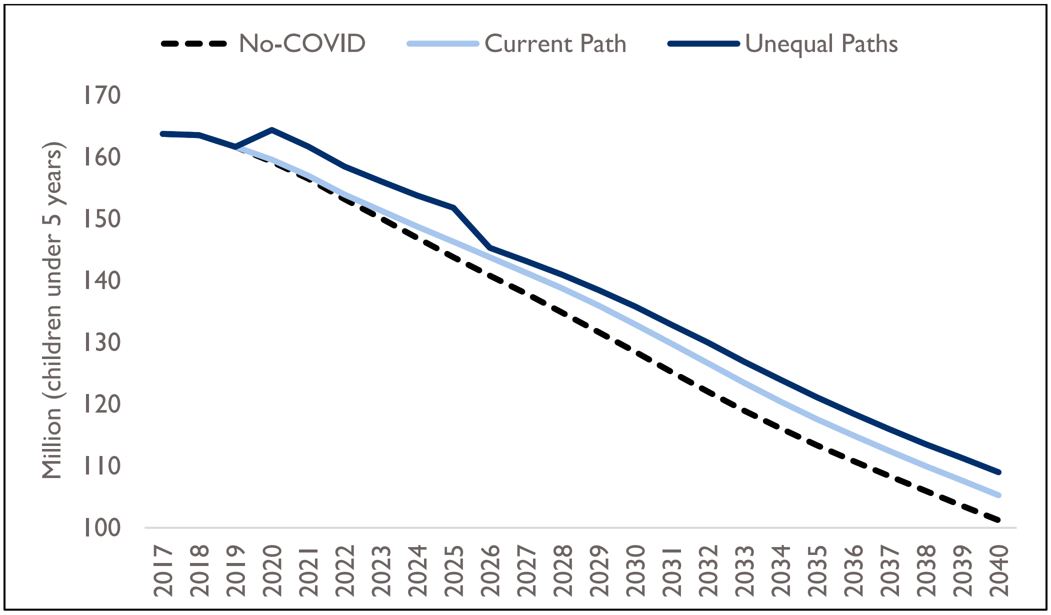
4.3 COVID-19 and child stunting

4.3.1 Trends in child stunting to 2040 with COVID-19

Child stunting over long periods of time is driven not only by caloric availability and household income but also by the development of educational initiatives directed at parents, access to WATSAN, and to health care that can help prevent the spread of communicable diseases (Vaivada et al. 2020). COVID-19 is affecting all these factors but impacts on reduced maternal education and government finances for WATSAN will manifest over longer time horizons. The challenge today is that reports on stunting and wasting generally rely on household surveys, and social distance measures imposed by COVID-19 largely halted household surveys in 2020 (UNICEF, WHO, and World Bank Group 2021). Thus, we have very limited evidence on how COVID-19 is affecting child malnutrition and child stunting on a global scale. One recent study using model projections estimates that by 2022 a cumulative 1.5 to 3.6 million additional children will be stunted globally, depending on the scenario, relative to a world without COVID-19 (Osendarp et al. 2021). This section will move beyond the 2022 timeframe and focus on the longer-term effects on stunting of COVID-19.

[18] When analyses were conducted for this report, GDP growth projections of April 2021 did not account for new variants and rises in spread of the virus. This effect is likely most pronounced in Southern Asia, with high spread and associated mortality from the COVID-19 Delta variant. Since we had already included in our study a downward scenario with a -1.5 percent adjustment in GDP growth, we believe the scenario framework does account for worsening outlooks of COVID-19 spread and the effects on economic and human development.

Figure 10: Global child stunting across the three scenarios, projected out to 2040.



Note: Projections start in 2017.
Source: Authors' calculations.

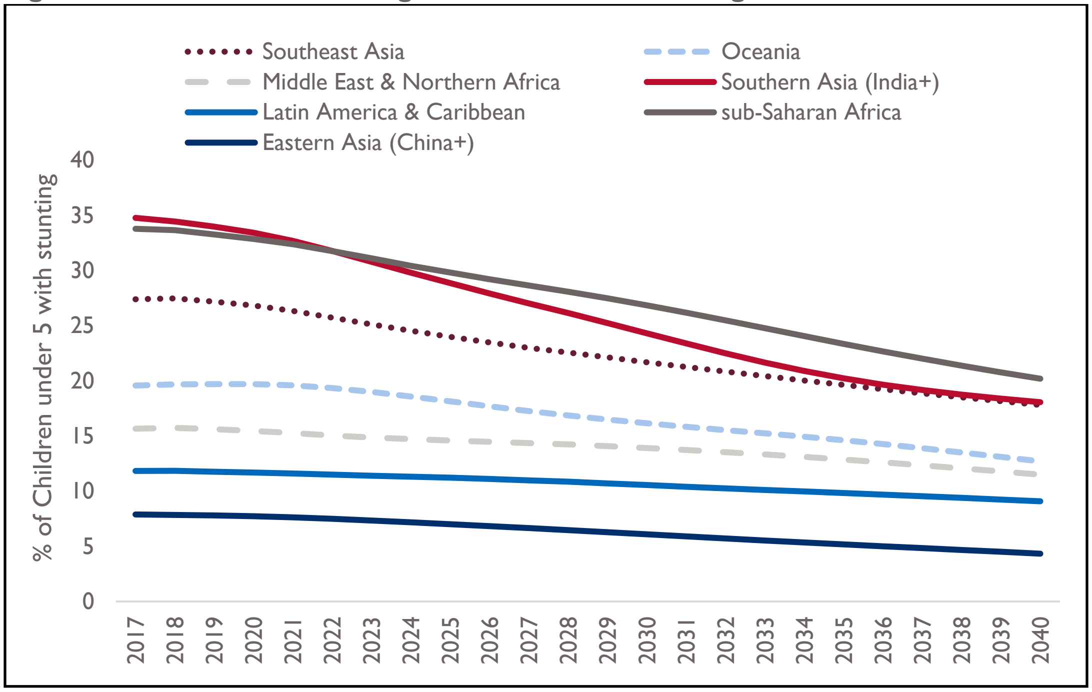
In 2020, we estimate that in the *Current Path* scenario, child stunting affects 159.6 million children under age five, a small increase from 159.3 million children in a *No-COVID* scenario. By 2022 the cumulative difference in child stunting is projected at 1.6 million additional children under five, close to the 1.5 million in the optimistic scenario from the only other existing forecast on child stunting (Osendarp et al. 2021). In the more pessimistic *Unequal Paths* scenario, child stunting is estimated to have risen further to 164.4 million in 2020 and continues to rise to 8 million additional children in 2025, relative to a *No-COVID* scenario (Figure 10), and to have risen slightly to 23.8 percent in 2020. Our estimates are similar to the findings of the Joint Malnutrition Report, which estimates an increase in child stunting from 21.3 percent in 2019 to 22.0 percent in 2020, or an estimated 5.2 million additional children (UNICEF, WHO, and World Bank Group 2021). We estimate child stunting in 2020 affected 159.6 to 164.4 million children, depending on the severity of COVID-19. The *Current Path* scenario is thus more aligned with a mild optimistic scenario (Osendarp et al. 2021), whereas the *Unequal Paths* scenario is more aligned with estimates from the Joint Malnutrition Report and more pessimistic than any of the projections by Osendarp et al. (2021).

Prevalence of child stunting

COVID-19 resulted in a rise in child stunting in 2020, but the effects of the pandemic are projected to manifest over time, with stronger effects seen from 2030 to 2040.

Child stunting is projected to drop, with and without COVID-19, to 14.9 percent in 2040. In 2020, child stunting was most prevalent in sub-Saharan Africa and Southern Asia, followed by Southeast Asia, Oceania, the Middle East, and North Africa (Figure 11). Child stunting is thus most prevalent today in Asian countries, with Southern Asia (57.3 million) and Southeast Asia (16.2 million) dominating, followed by sub-Saharan Africa (57.3 million). Progress on eradicating child stunting is projected to be especially strong in Southern Asia, dropping from 33.6 percent in 2020 to 18.4 percent in 2040 and, to a lesser extent in sub-Saharan Africa, dropping from 32.9 percent in 2020 to 20.1 percent in 2040, and Southeast Asia, dropping from 26.8 percent to 17.8 percent. By 2040 this means that more children suffering from stunting are projected to live in sub-Saharan Africa (47.4 million) than in Southern Asia (30.1 million) and Southeast Asia (9.4 million) combined. This rate of progress is similar to a recent global statistical modeling forecast for 2030 by FAO et al. (2021).

Figure 11: Rates of child stunting for the different world regions for the *Current Path* scenario.



Note: World regions with child stunting rates below 5 percent are not depicted.
Source: Authors' calculations.

4.3.2 Quantifying the effect of COVID-19 on child stunting in 2020 and 2040

The effect of COVID-19 on child stunting is less than its effect on both extreme poverty and undernourishment. By 2040, child stunting rates are projected to increase from 14.5 percent in a *No-COVID* scenario to 14.9 percent or 15.4 percent, depending on the COVID-19 scenario. COVID-19, and associated economic contractions, are also slightly increasing the projection of total fertility rates and the number of children under age five out to 2040. Combined, the rise in absolute child stunting from COVID-19 out to 2040 is equivalent to 4.0 to 7.7 million additional children suffering from stunting, or a one- to three-year setback in progress.

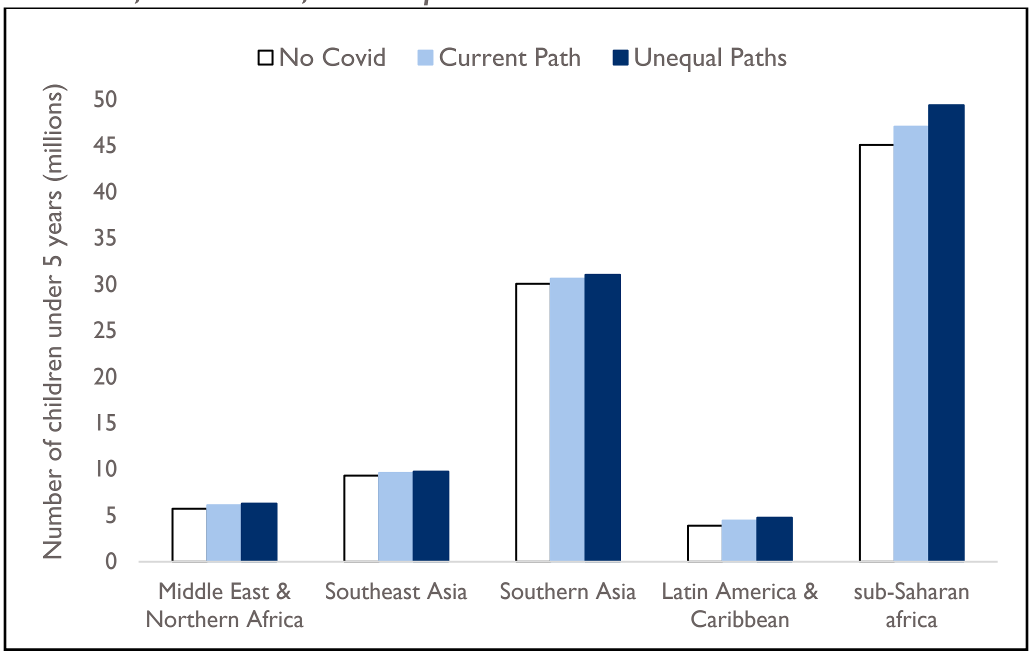
In contrast to the effects of the pandemic on poverty or undernutrition, COVID-19 is producing a negative long-term effect on the drivers of stunting out to 2040, with effects on water and sanitation infrastructure as well as effects on maternal education manifesting slowly over time. Scenario projection lines for extreme poverty and undernourishment remain relatively parallel after 2025 following an increase due to the COVID-19 shock. The opposite is true for child stunting, with initial small effects of due to COVID-19 and gradual divergence of the scenarios after 2025 (Figure 10). This shows the importance of longer-term effects on education and access to WATSAN on limiting child stunting.

Child stunting

Child stunting is driven by access to water and sanitation and maternal education. Both drivers are affected in the long run by lower economic growth, reduced government finances and the long-term effects of education losses due to COVID-19.

Regionally, the effect of COVID-19 on child stunting falls primarily to sub-Saharan Africa, with much smaller increases in Southern Asia and Latin America and the Caribbean (Figure 12). Under our projection, child stunting in sub-Saharan Africa increases by 2040 by 2.0 million to 4.3 million, relative to a *No-COVID* scenario. All other world regions show increases in child stunting of under one million. Of additional children suffering from child stunting out to 2040, 52 to 60 percent are projected to live in sub-Saharan Africa.

Figure 12: Absolute number of children under 5 years suffering from child stunting in 2040 in the *No-COVID*, *Current Path*, and *Unequal Paths* scenarios.



Note: World regions with values below 3 million children stunted are not depicted.
Source: Authors' calculations.

5. Pathways of change: Trends in underlying drivers of food availability, access, and utilization, and the effect of COVID-19 thereon

Purpose: This section goes beyond the results presented in Section 4, to quantify trends in the drivers of food availability, access, and utilization to 2040, with and without COVID-19, and the effect of COVID-19 thereon. Understanding the contributions of drivers to food security by 2040 at the world and world region level helps in identifying policy priorities to improve food security and to minimize the negative effects of COVID-19 thereon.

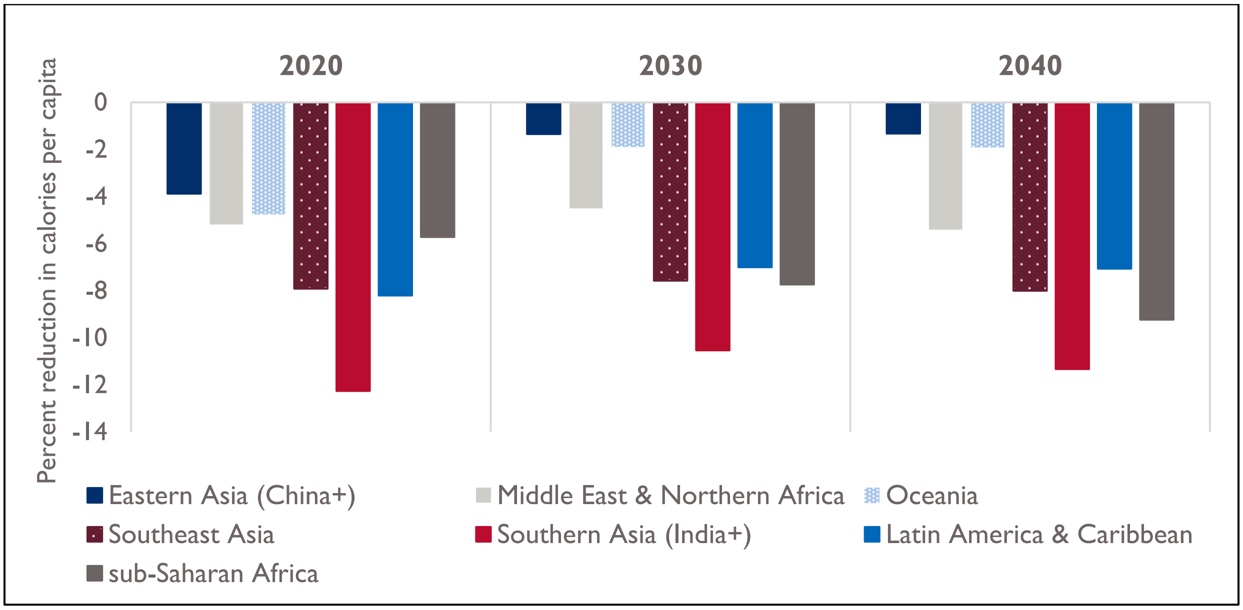
5.1 COVID-19 and food access to 2040

Effects of COVID-19 on food security

The effects of the COVID-19 pandemic on food security indicators in 2020 and out to 2040 are driven primarily by reduced food access as a result of changing economic growth, household incomes, and rising inequality.

In Section 4, we quantified and discussed several ways COVID-19 is likely to hinder progress on indicators of human well-being, but only touched briefly on the pathways through which it operates. Insights from previous sections and from literature identified household income, inequality, and food prices as three of the strongest drivers of this setback. Starting in 2020, COVID-19 and the policies that governments, businesses, and civil society put in place to control the spread of the pandemic resulted in significant increases in unemployment and underemployment, contributing to an estimated global reduction in household earnings of about 4 percent in 2020 (about 6 percent lower than what would have been expected in a world without COVID-19). Relative to the *No-COVID* scenario, regional impacts range from less than 4 percent in Eastern Asia (primarily China) to over 12 percent in Southern Asia (primarily India), with most regions returning to pre-COVID 2019 per capita income levels in one to two years. However, while average GDP per capita may return relatively quickly to pre-COVID levels, the recovery may be unequal among groups. For example, female employment has been disproportionately affected by the pandemic, which may have long-term consequences for progress on gender equality. Even with the projected recovery, the resulting reduction in caloric demand, as measured by calories per capita, and the challenges to its equal distribution, approximated by the coefficient of variation, as well as longer-term reductions in government finance and education, are expected to have lasting impacts on the global prevalence of undernutrition (Figure 13).

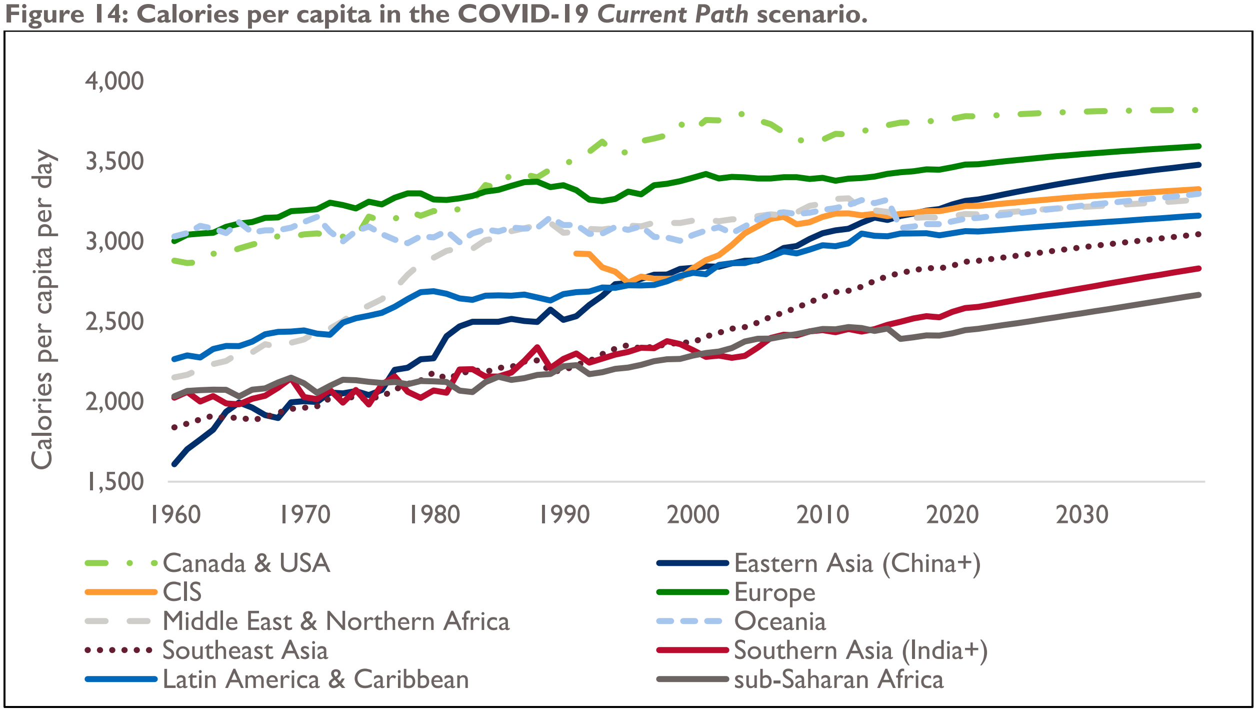
Figure 13: Percent reduction in calories per capita in the *Current Path* scenario relative to the *No-COVID* scenario.



Source: Authors' calculations.

With or without COVID-19, per capita demand for calories will remain significantly higher through 2040 in high-income regions such as Canada and the U.S., and Europe (Figure 14). While calories per capita in sub-Saharan Africa and South Asia will maintain steady growth, they are not expected to reach levels seen in the U.S. and Europe 60 years ago. This is in stark contrast to East Asia (primarily China), which saw nearly a doubling of demand over the last 60 years and is expected to reach today's European levels of demand by 2040.

Figure 14: Calories per capita in the COVID-19 *Current Path* scenario.



Source: Authors' calculations.

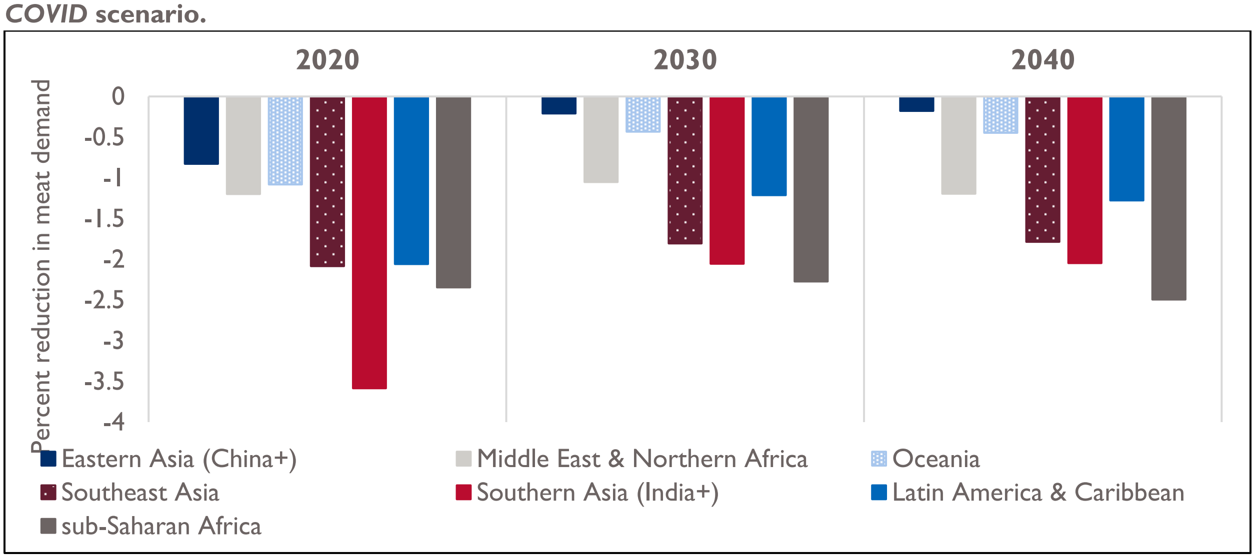
Household income

Drops in household income drive down caloric intake across world regions in 2020 and out to 2040. Households adjust by shifting a larger share of household spending to food and by shifting diets away from meat toward staple crops. However, these shifts lower dietary diversity and make households more vulnerable to future shocks.

We estimate that in 2020, Southern Asia (primarily India) experienced a 1.3 percent reduction in calories per capita relative to a *No-COVID* scenario, double that of all other regions except for Southeastern Asia. As a country hit particularly hard by the pandemic, India experienced a 10 percent reduction in GDP per capita (measured in purchasing power parity), resulting in a 1.4 percent reduction in calories per capita and a 10 percent increase in the prevalence of undernourishment relative to the *No-COVID* scenario (from 13.1 percent in *No-COVID* scenario to 14.4 percent in the *Current Path* scenario). A similar story emerges in sub-Saharan Africa, where a 5.4 percent decrease in GDP per capita resulted in a 0.6 percent reduction in caloric demand. While household incomes have taken a hit, and extreme poverty has risen in 2020, the effects on caloric demand per capita is lessened.

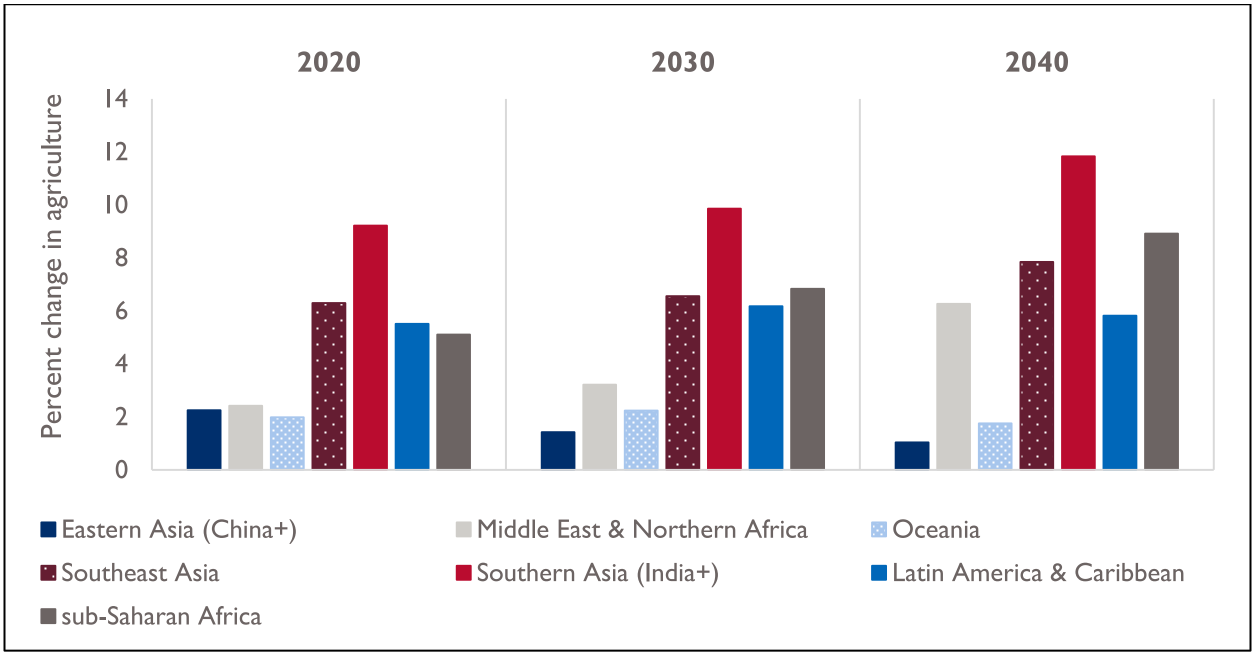
To lessen the impact on their food baskets, many households are expected to shift consumption away from meat (Figure 15) toward less expensive, crop-based foods. While this shift is expected to be strongest and most enduring in Southern Asia and sub-Saharan Africa, which face the largest demand reductions because of the pandemic, diets of these regions are already far less meat intensive than those of higher-income countries. Consumers may also choose to forego the purchase of information and communication technologies and other manufactured goods or services to allocate more income toward the consumption of food (Figure 16). But since the most vulnerable regions already spend the largest portion of their income on food, shifting diets and consumption patterns may be less of an option for many poor to near-poor households. Shifts in dietary and consumption patterns also pose a risk due to 1) the reduction in dietary diversification, and 2) an increased vulnerability to future shocks to household income and food security from climate, weather, conflict, economic, or health-related changes. While we do not fully assess the effect of COVID-19 on dietary quality, an overview of current understanding is given in Box 3: COVID-19 and dietary quality.

Figure 15: Percent change in meat demand as a portion of total caloric demand relative to *No-COVID* scenario.



Note: Given that changes in undernourishment are negligible in Canada and U.S., Europe, and Commonwealth of Independent States, we did not depict changes in those regions.
Source: Authors' calculations.

Figure 16: Percent change in share of household consumption going to food (agriculture) relative to *No-COVID* scenario.



Note: Given that changes in undernourishment are negligible in Canada and the U.S., Europe, and Commonwealth of Independent States, we did not depict changes in those regions.
Source: Authors' calculations.

Within a country, significant variations in income and consumption between households also means varying resilience to shocks. The Gini index measures the degree of income inequality within a country and has been shown to be an important driver of the change in poverty. The coefficient of variation is a measure used to describe the distribution of calories within a population and is similar to the Gini index of income inequality. Given that access is primarily a question of income and food prices, income inequality is often regarded as a driver of the distribution of calories within a population. According to model-based estimates of the coefficient of variation,[19] sub-Saharan Africa has one of the most unequal distributions of calories in the world, though the region is also home to some of the most equal and unequal countries of the world.

The IFs model can both endogenously and exogenously project the distribution in household income and calories. However, to assess the effect of COVID-19 on income and food distribution, we opted to exogenously impose increases among countries of either a one or two percent rise in inequality of the income and caloric distribution (see Section 3 for scenario assumptions). Exogenously prescribing these values limits our ability to fully assess the contribution of inequality in the future of food security. However, individual countries can teach us something about the relative dynamics of overall growth in caloric demand versus the distribution thereof. Box 2 further explores some of the dynamics surrounding overall demand for food and distribution of calories using the Central African Republic and Zimbabwe as examples. In addition, in Appendix D we explore the relative importance of changes in GDP growth and distribution of household income and calories.

[19] For this study, we infer the coefficient of variation using estimates of the prevalence of undernutrition, the minimum dietary energy requirement, and an assumption of lognormality in caloric distribution. A sensitivity analysis exploring the impact of different distributional patterns on undernutrition is provided in Appendix D.

While it may be some time before we fully understand the multiple ways COVID-19 has disrupted access to food, the impact is likely shouldered disproportionately by those already in positions of relative insecurity. This is true at the country and world region levels, as well as for individual households within countries. And while the pandemic is expected to set back progress toward the elimination of undernutrition, it also highlights important structural distinctions regarding demand and distribution that governments and relief organizations should consider in their efforts to achieve zero hunger.

5.2 COVID-19 and food availability to 2040

Reduced household incomes and changes in the distribution of income and calories are primary pathways by which COVID-19 is affecting food security. However, reductions in agricultural demand also have forward effects on food availability. Globally, reductions in agricultural demand are mirrored by reductions in agricultural production. In other words, a core assumption in the IFs model is that the world does not produce more food than it can consume. The COVID-19 pandemic and its consequences do not alter the biophysical conditions for production, such as, for example, does climate change. Therefore, the main effect of COVID-19 on food availability does not operate through net reductions at the country or global level, but rather shifts in what and where food is being produced.

Food availability

COVID-19 has minimal effects on food supply and availability today and is projected to also have little effect out to 2040.

Shifting diets and growing populations result in a continued increase in demand for food. Over the past decades, increases in food production have been fueled by rapidly increasing yields in Europe, Canada, and the U.S., followed by a combination of yield and land expansion in Southeast Asia, Eastern Asia, especially China, and countries in Latin America and the Caribbean and Southern Asia. However, many countries are reaching limits on land expansion as well as limits on yield increases (Eitelberg, van Vliet, and Verburg 2015; van Zeist et al. 2020), meaning that further increases in agricultural production will primarily derive from expansion of yields and land in sub-Saharan Africa and further increases in Southern Asia.

Box 2: Demand, distribution, and undernourishment in Central African Republic and Zimbabwe.

In 2020, the Central African Republic and Zimbabwe both had similar levels of undernutrition (53 percent and 52 percent respectively) even though, at about 2,200 calories per capita, Zimbabwe has notably higher demand than the Central African Republic. In fact, the Central African Republic's caloric demand is only about 8 percent higher than the minimum energy dietary requirement, whereas Zimbabwe is more than 25 percent above the threshold. However, in the Central African Republic the distribution of calories, captured by the coefficient of variation, is more equal compared to Zimbabwe. The comparison of these two countries with similar PoU offers insights into the ways in which shocks and progress may play out among countries that differ in terms of initial conditions of overall calories per capita, caloric distribution, and food consumption shares. It also gives policy makers insights into why progress on undernourishment in 2040 may strongly differ from today, and why the effects of COVID-19 differ among countries.

Table 3: Key food security indicator estimates for Central African Republic and Zimbabwe in 2020.

	Key food security indicators in 2020	
	Central African Republic	Zimbabwe
Prevalence of undernourishment	53.1	51.6
Calories per capita	1,827	2,166
Coefficient of variation	0.16	0.72
Agriculture share of consumption	56	25
Percent increase in undernutrition	4.2	1.8

Before COVID-19, more than half of household consumption in the Central African Republic was on food. In Zimbabwe, this figure was less than one quarter. With a larger portion of food consumption exposed to the shock induced by COVID-19, the prevalence of undernourishment in Central African Republic was estimated to have increased by 4.2 percent in 2020, relative to the *No-COVID* scenario, while Zimbabwe's undernutrition increased by only 1.8 percent, with the share of household food consumption increasing by over 11 percent.

Box 2: Continuation.

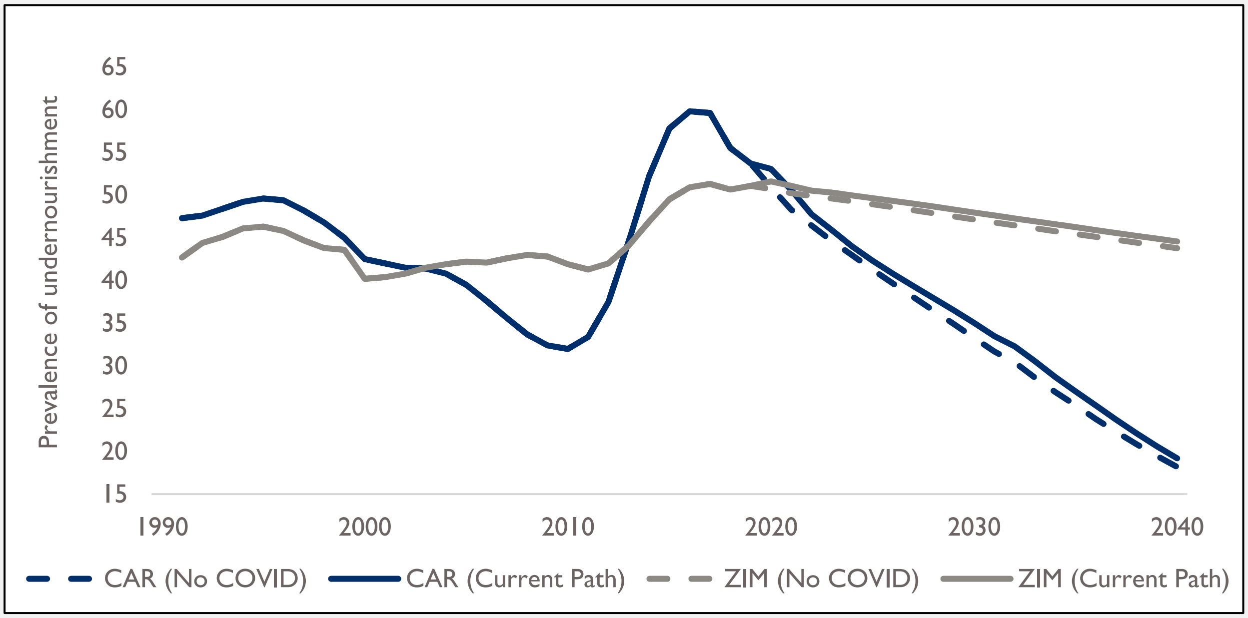
But the Central African Republic's relatively larger setback from COVID-19 is minor when compared to the progress in eliminating hunger the country is expected to make in the long run, even despite maintaining one of the lowest levels of caloric demand on the continent. This is due to the country's equal distribution of calories.

Historical estimates of caloric distribution are hard to come by, but archived data from FAO suggest that the global (simple) average change in the coefficient of variation was negligible from 2000 to 2016. Even among countries that made progress, the average reduction in inequality was less than 1 percent (though China and Brazil managed an average annual improvement of 2.1 percent and 1.8 percent over the period).

Demand in the Central African Republic and Zimbabwe are both projected to grow at a similar rate over the coming decades. Calories per capita in the Central African Republic, which start from a much lower base, are not expected to reach levels seen in Zimbabwe today until nearly 2050. Nevertheless, because the Central African Republic's low inequality means that gains in caloric demand translate more rapidly toward the reduction of hunger, by 2040 only 19 percent of the population is expected to be undernourished, whereas undernourishment levels in Zimbabwe are projected to be twice that.

For both countries, COVID's impact on the prevalence of undernourishment expands slightly by 2040 (a 5.5 percent increase in the Central African Republic and a 1.8 percent increase in Zimbabwe, relative to the *No-COVID* scenario). For the Central African Republic, this increase is hardly noticeable compared to the significant reduction expected over the coming decades. However, for Zimbabwe, which due to its inequality is projected to reduce undernutrition by only 13 percent between today and 2040, this represents a much more visible scar.

Figure 17. Prevalence of undernourishment for the Central African Republic and Zimbabwe under the *Current Path* and *No-COVID* scenarios.

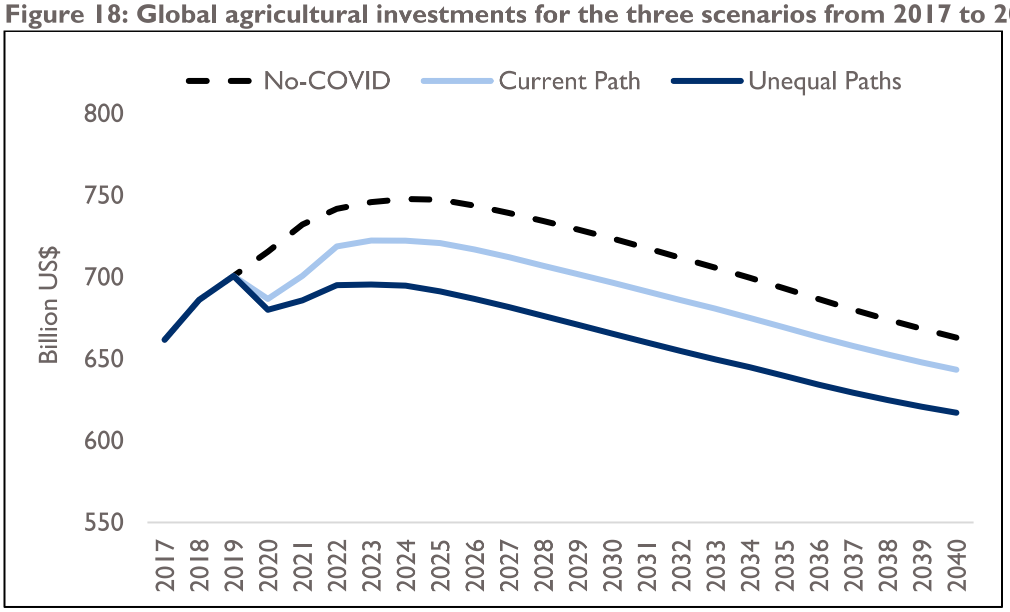


Note: CAR = Central Africa Republic, ZIM = Zimbabwe
Source: Authors' calculations.

A rise in agricultural production requires investment. Agricultural investment is projected to drop globally and among several world regions by 2040, after an initial rise through 2025 (Figure 18). The only three world regions with projected growth in agricultural investments during that period are Eastern Asia, Southern Asia, and sub-Saharan Africa. However, the economic downturn of COVID-19 is projected to reduce agricultural investment globally, and especially in these three regions, as well as in Latin America and the Caribbean. By 2040, the cumulative reduction in agricultural investment is projected to result in a -8.1 percent to -12.0 percent decline in Southern Asia, -6.0 percent to -9.2 percent in Southeast Asia, -5.6 percent to -10.4 percent in sub-Saharan Africa, and -5.8 percent to -8.8 percent in Latin America and the Caribbean (Table 4).

This reduction in agricultural investment has a dual effect on food security: 1) it limits the transition from an agriculture-based society to a more diversified economy, partly keeping populations in a rural poverty trap, especially in areas projected to make the strongest transition in the next decades, and 2) it drives down expansion of agricultural yields and land under cultivation in regions that need to realize the largest rise in production in order to become self-sufficient.

Figure 18: Global agricultural investments for the three scenarios from 2017 to 2040 in billion US$.



Source: Authors' calculations.

Reductions in agricultural investment have consequences for domestic agricultural production, from land expansion to productivity. Total agricultural land expansion is projected to drop for all world regions because of COVID-19 (Figure 19). In Southern Asia, there is almost no net change projected in agricultural land, with or without COVID-19. In the other world regions, however, agricultural land expansion is projected, with the largest rise in sub-Saharan Africa. COVID-19 slows this agricultural land expansion from 31.9 Million Hectare (MH) in a *No-COVID* scenario to 29.3 MH and 27.4 MH in the *Current Path* scenario and *Unequal Paths* scenario, respectively.

Agricultural investment

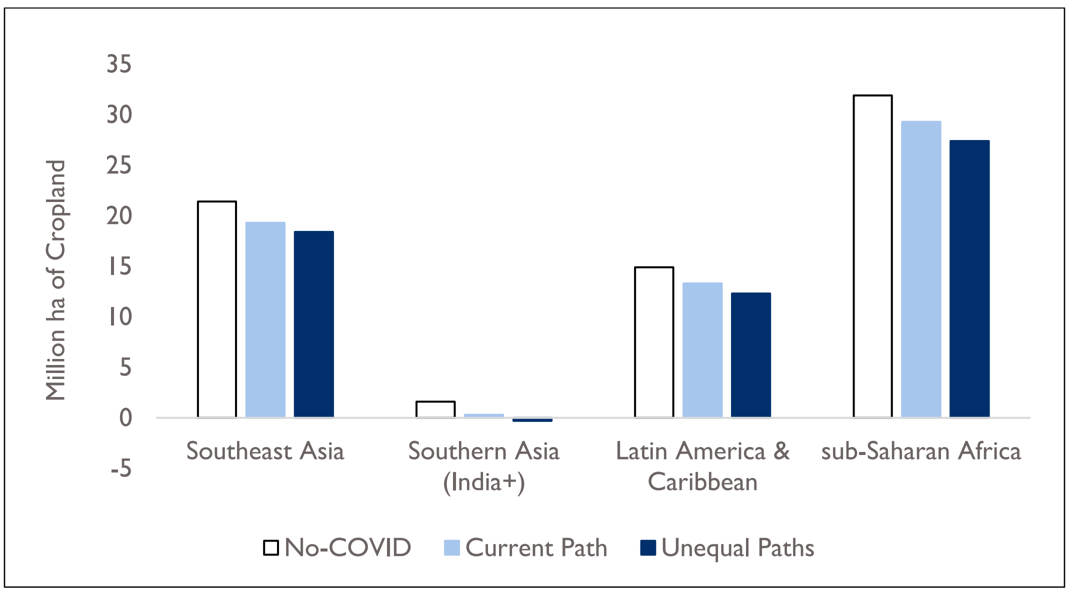
The reduction in economic activity due to the COVID-19 pandemic is projected to reduce investment in agriculture out to 2040, with the largest drop in the most food insecure regions of sub-Saharan Africa, Southern Asia, Latin America and Caribbean, and Southeast Asia.

Table 4: Cumulative agricultural investments per world region for the period 2020–2040 in billion US$, for the *No-COVID* (NC), *Current Path* (CP), and *Unequal Paths* (UP) scenarios.

Region	Cumulative agricultural investments (2020–2040) in billion US$			Percent decline	
	NC	CP	UP	NC to CP	NC to UP
Eastern Asia	7,042.4	7,020.9	6,802.5	-0.3 percent	-3.4 percent
Southeast Asia	1,653.1	1,553.7	1,501.0	-6.0 percent	-9.2 percent
Southern Asia	2,938.8	2,701.2	2,585.1	-8.1 percent	-12.0 percent
Oceania	176.1	174.3	168.4	-1.0 percent	-4.4 percent
Latin America and the Caribbean	733.8	691.4	669.3	-5.8 percent	-8.8 percent
Middle East and North Africa	1,211.4	1,193.8	1,155.1	-1.5 percent	-4.7 percent
sub-Saharan Africa	1,243.7	1,173.4	1,114.7	-5.6 percent	-10.4 percent

Note: The columns at the right show the relative decline in agricultural investments.
Source: Authors' calculations.

Figure 19: Change in cropland between 2017–2040 for four world regions, for the three scenarios in Million Hectare.



Note: Results are only depicted for the four world regions with the largest change in agricultural investment.
Source: Authors' calculations.

The other component of the agricultural production system is agricultural productivity, measured as yields per hectare. It varies among world regions because of crop composition, biophysical conditions, and management practices. To assess the management intensity of production among world regions, we focus on yield intensity, the difference between the potential and actual production, which controls for crop types and climatic differences. A yield intensity of one (1) means that production cannot be further increased with currently available management techniques.

In sub-Saharan Africa, yield intensities are relatively low, showing potential to further increase yields by optimizing management techniques. In Southern Asia and Latin America, there is wider variation in yield intensities among countries. But on average, yield intensities in those regions are lower than in Canada and the U.S. or Western Europe. In Eastern Asia and in some Southeast Asian countries, yield intensities come close to biophysical maxima, reaching levels like the U.S., Canada, and many European countries.

Agricultural yield

Agricultural yields in sub-Saharan are projected to increase over the next two decades, but the region will still perform at a lower level than other regions.

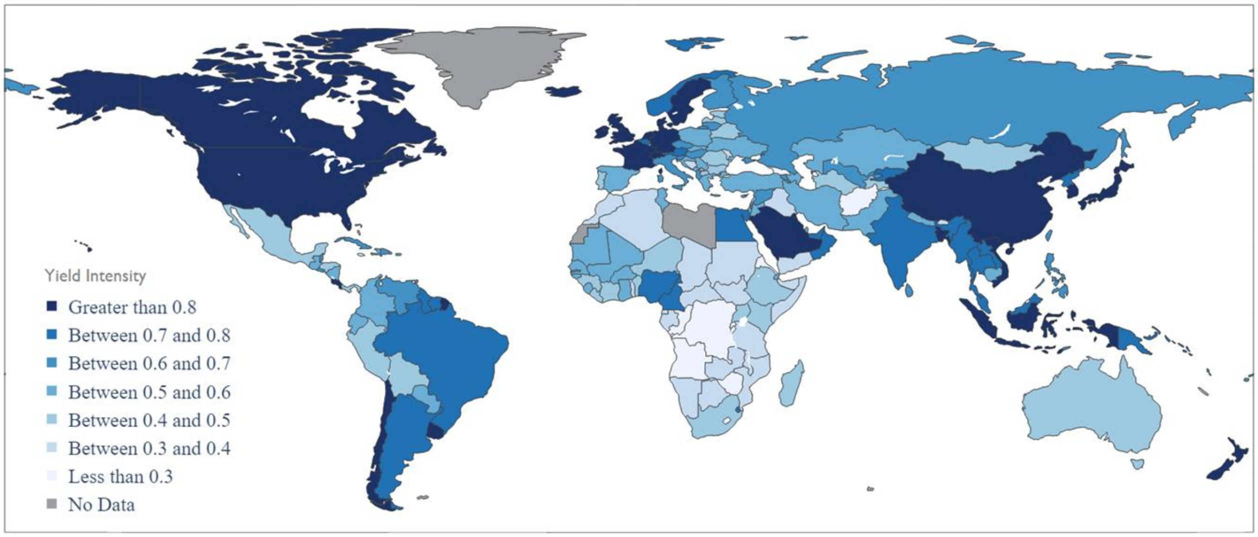
Between 2020 and 2040, the rise in yield intensities is projected to be highest in sub-Saharan Africa, but even by 2040 the average yield intensity does not reach the level of Southern Asia today (the region with the second-lowest yield intensities), demonstrating the struggle to increase yields in many African nations (Figure 20). The effect of COVID-19 on yield intensities is minimal, with reductions about 0.01 or 1 percentage point. Thus, reductions in agricultural production at the regional level from COVID-19 operate primarily through a reduction in land expansion.

The projected shifts in agricultural production make countries in sub-Saharan Africa even more reliant on food imports to meet increasing demands, and further decrease their degree of food self-sufficiency. While food self-sufficiency is not a direct indicator of food security, it is often an indicator of food security risk. Higher food import dependence makes countries more vulnerable to global economic shocks, food trade restrictions, and price fluctuations (as seen in the COVID-19 era), and low-income countries generally lack infrastructure and foreign exchange reserves to pay for food imports and store food appropriately (van Ittersum et al. 2016). Already today, sub-Saharan Africa has some of the lowest food self-sufficiency ratios of any world region, and rising populations will put increased pressure on meeting agricultural demand through domestic production.

By 2040, increases in agricultural production cannot, under our projections, keep up with population increases and rising agricultural demand in sub-Saharan Africa and the Middle East and North Africa (Figure 21). And almost no country will be food self-sufficient.[20] In Southern Asia, Latin America, Southeast Asia, and Eastern Asia, most countries have food self-sufficiency ratios at or below one, with a smaller subset of countries with values above one. Food self-sufficiency ratios above one are observed in Australia and New Zealand, North America, and especially countries in the Commonwealth of Independent States. COVID-19 is changing this pattern only slightly, with most countries experiencing limited effects on food self-sufficiency (between -0.01 and +0.01). However, a clear pattern in self-sufficiency trends is emerging. Countries with lower food self-sufficiency ratios because of COVID-19 are low- to low-middle-income economies, with already low levels of food security, such as Republic of Congo, Democratic Republic of Congo, Madagascar, and Chad. Countries with rising food self-sufficiency ratios tend to be upper-middle-income and high-income economies, with high projected levels of food security, such as Iceland, Australia, New Zealand, and Uruguay.

[20] The food self-sufficiency ratio is calculated as the share of total domestic agricultural production relative to total domestic demand.

Figure 20: Agricultural yield intensity index (0-1) per country, for the *Current Path* scenario in 2040.



Note: A value of one (1) indicates full intensity, i.e., current agricultural yields are equivalent to potential yields. Libya is excluded from the analysis throughout the report.
Source: Authors' calculations.

Overall, by 2040, the world is projected to produce enough food to eradicate hunger, and country-level food availability from domestic production and trade is sufficient to meet demand. Irrespective of COVID-19, the world is projected to increase agricultural demand and food production. Increases in land under cultivation and yield intensity drive rising food production, especially in Southern Asia and sub-Saharan Africa. However, the rapid rise in populations means that sub-Saharan Africa will experience decreasing levels of food self-sufficiency and become even more dependent on food imports. COVID-19 may worsen this outlook by reducing agricultural investments and shifting production away from countries in sub-Saharan Africa. Overall, policies aimed at increasing agricultural production in food insecure countries are needed to increase food self-sufficiency. But they will only be effective in reducing food insecurity at the household level if met by increases in both household income and agricultural demand.

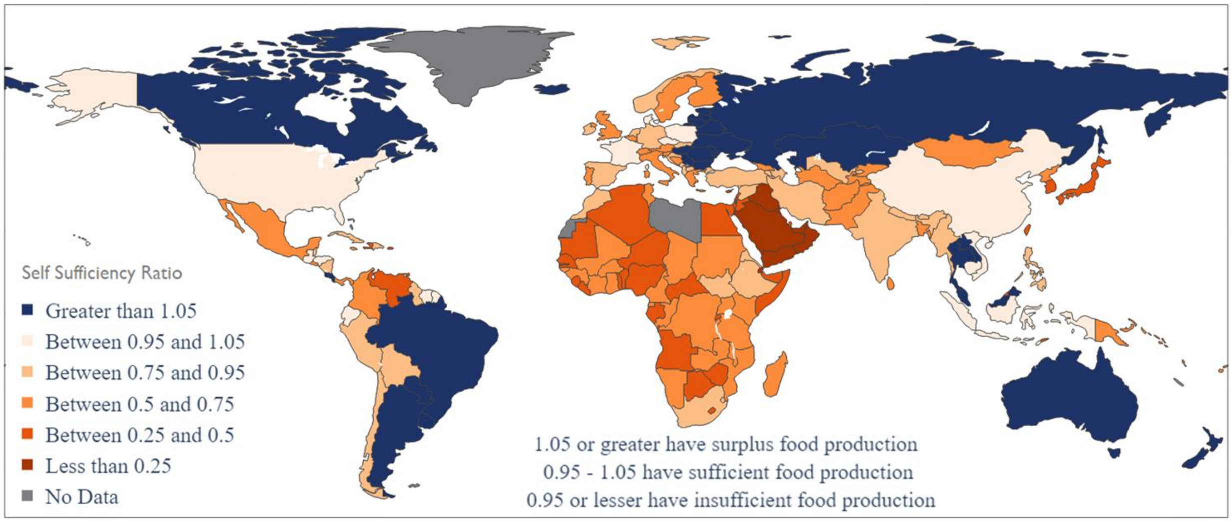
Food self-sufficiency

The effects of the COVID-19 pandemic are projected to further drive down food self-sufficiency for some countries in sub-Saharan Africa, Southern Asia, and Latin America, including the Democratic Republic of Congo, India, and Madagascar.

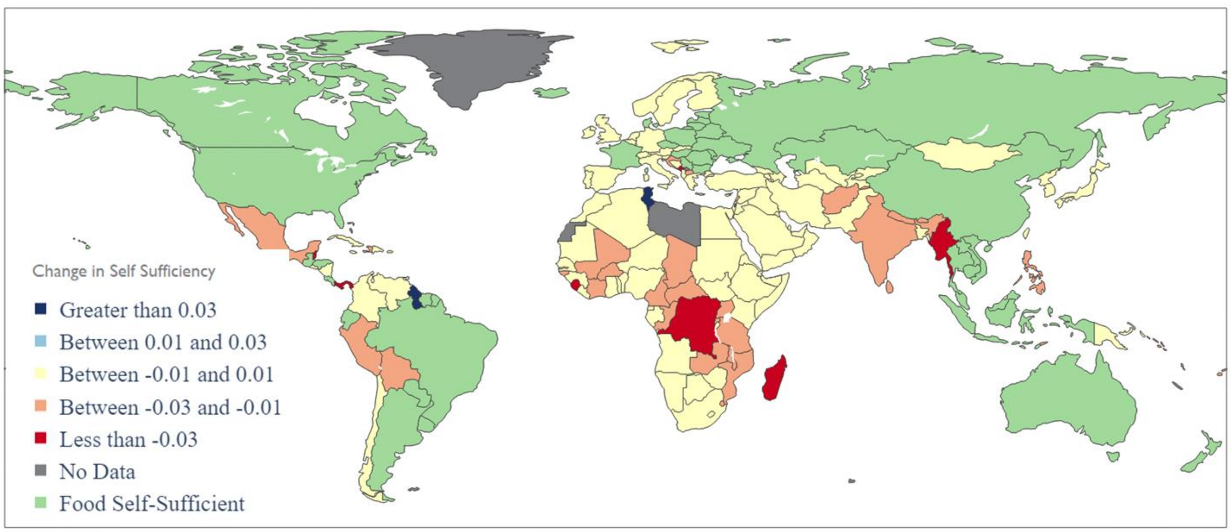
The top panel in Figure 21 depicts the food self-sufficiency ratio in 2040 for the COVID-19 *Current Path* scenario. The bottom panel depicts the change in food self-sufficiency in 2040, between a No-COVID scenario and the *Current Path* scenario, for all countries that are not food self-sufficient in 2040. Libya is excluded from all analyses in the report.

Figure 21: Food self-sufficiency ratio in 2040, *Current Path* scenario (top panel) and change in food self-sufficiency ratio in 2040 between the No-COVID and the *Current Path* scenario (bottom panel).

Food self-sufficiency ratio



Change in food self-sufficiency ratio



Source: Authors' calculations.

5.3 COVID-19 and food utilization to 2040

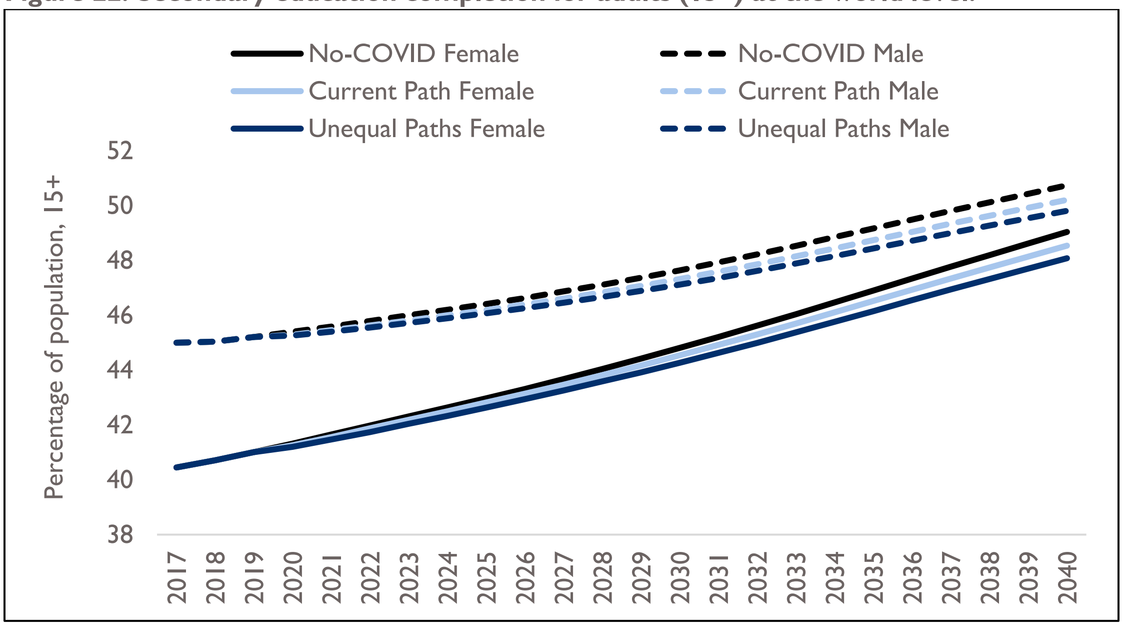
Food utilization is an important contributor to food security, especially for children. It relates to household income and caloric demand, in combination with broader indicators of household environments and general human development in countries, such as safe access to WATSAN, health care access, and parental, and especially, maternal education. The previous section already looked at progress in calories per capita, so here we primarily focus on progress in education and access to WATSAN. Dietary quality is also important for food utilization and discussed in Box 3: COVID-19 and dietary quality.

The effects of COVID-19 on these indicators are both direct and longer-term. School closures result in immediate learning losses. Slower economic growth, reduced household income, and reduced government spending create longer-term effects on education and access to WATSAN. These effects take time to manifest. COVID-19 is not impacting WATSAN infrastructure directly, but reduced government spending on such infrastructure will limit general progress for this indicator over time. Education losses are direct for children. However, forward effects of lower education levels in the adult population on human capital, economic growth, and child stunting take time to show, because children need to age before they are counted in the adult population. Lower secondary education completion rates can be a direct outcome of COVID-19, but forward effects will linger for at least a generation. A second important consideration is that changes in education levels of adult populations may seem incremental because effects on the COVID-19 generation get averaged out across the entire adult population of a country.

COVID-19 and broader development

School closures result in immediate learning losses, but the effects on economic growth and human development manifest over time.

Figure 22: Secondary education completion for adults (15+) at the world level.



Note: We make a distinction between female and male adult education completion rates for the three scenarios
Source: Authors' calculations.

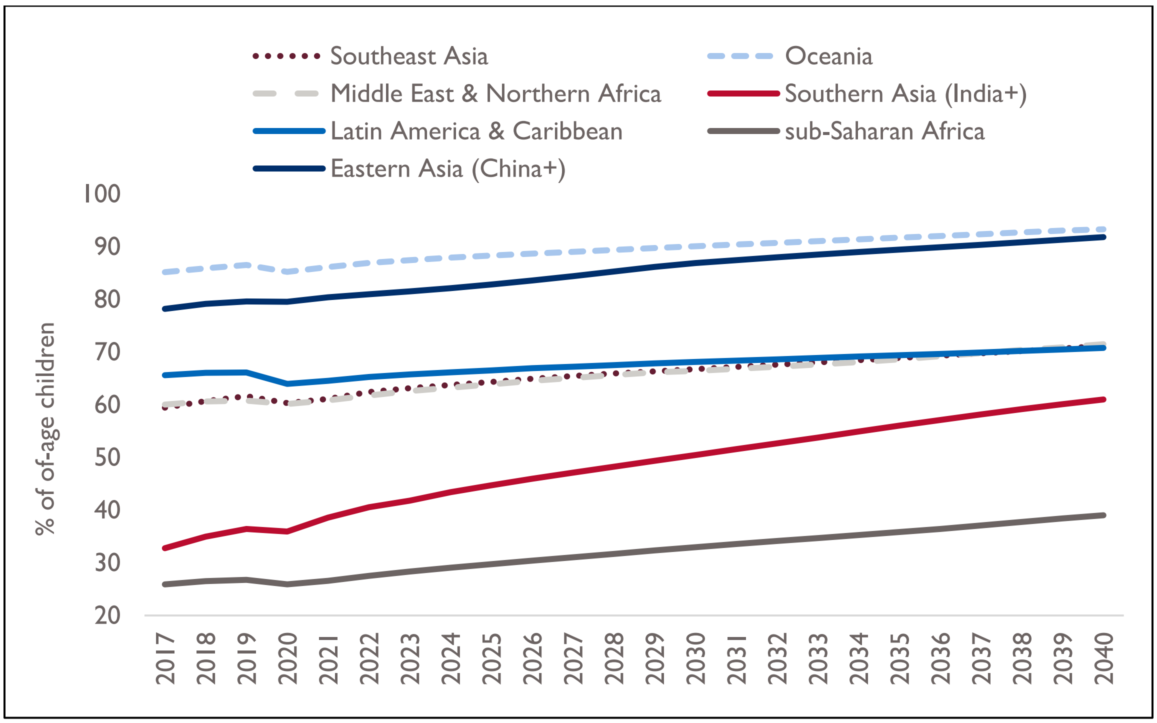
Higher levels of education, particularly of females, are development goals in and of themselves, with positive forward synergies for broader human development. Secondary education levels have risen significantly in the last half century, with progress in North America, Europe, and the Commonwealth of Independent States from below 10 percent to over 70 percent of the adult population by 2015. In other world regions, progress has been less pronounced, with values remaining below 50 percent. In 2019, upper secondary graduation rates were high in Europe, North America, the Commonwealth of Independent States, and in Eastern Asia, the latter being mainly driven by rising educational levels in China. In Southern Asia and sub-Saharan Africa, upper secondary graduation rates of children remain below 50 percent, a potential development drag for the near future. While Southern Asia is projected to make rapid progress out to 2040, reaching levels of Southeast Asia today, progress in sub-Saharan Africa is likely to be much more subdued, with values not reaching above 50 percent of of-age children by 2040.

Secondary education completion

There are strong differences in secondary education completion between adult males and females and between world regions in 2020, with Southern Asia and sub-Saharan African only partly closing these gaps out to 2040.

Secondary education completion in 2020 is lower for females (*Current Path* scenario: 41.3 percent) than it is for males (*Current Path* scenario: 45.3 percent) (Figure 22). Over time, rising levels of education for girls results in a gradual closing of the gap between male and female education by 2040, irrespective of COVID-19. While all world regions show progress on secondary education completion for children, there is a strong difference between initial starting conditions (Figure 23). This slowdown in secondary education completion due to COVID-19 will slow progress in both male and female adult education levels.

Figure 23: Upper secondary completion rates for of-age children among world regions for the *Current Path* scenario.



Note: Only results for world regions with less than 90% of upper secondary completion rates are depicted.
Source: Authors' calculations.

COVID-19 is projected to reduce the size of economies and increase government debt. Consequently, expenditures on education are estimated to drop in 2020 and out to 2040. These effects are most pronounced in sub-Saharan Africa, Southeast Asia, and Southern Asia (Table 5).

A similar pattern is observed for access to water and sanitation. Given that both water and sanitation indicators follow similar trends, we focus here on access to improved sanitation[21]. At the global level,

[21] The IFs model follows the joint monitoring program for water supply, sanitation, and hygiene from WHO and UNICEF (https://washdata.org/monitoring/sanitation). Improved sanitation is everything at or above limited access to sanitation.

the population with access to improved sanitation is projected to rise from about 74.8 percent in 2020 to 84.7 percent in 2040 in the *Current Path* scenario (Figure 24). This rise comes on top of rapid progress since 2000, up from 55.2 percent that year to 73.6 percent in 2017, driven by rapid progress in Southern Asia and Eastern Asia, with considerably less progress over that period in sub-Saharan Africa.

Box 3: COVID-19 and dietary quality

Food security is multidimensional, dependent on both caloric intake and a diverse and healthy diet. In this report we focus on measures of caloric intake, given limitations on both the availability of data on dietary quality and on modeling frameworks to project dietary quality over longer periods of time.

The COVID-19 pandemic threatens progress on dietary quality both immediately and in the long term. Emerging evidence suggests that COVID-19 is negatively affecting dietary quality. Phone surveys of households in Burkina Faso, Nigeria, and Ethiopia suggest that dietary diversity in those countries, measured as the number of food groups consumed, has decreased as a consequence of COVID-19 (Madzorera et al. 2021). Similarly, model projections suggest that changes in household income and food prices have resulted in a global dietary trend in 2020 away from nutrient-rich foods (such as fruits, vegetables, dairy, and meat) and towards staple crops (Laborde, Martin, and Vos 2021). As a result of COVID-19, projections on child and maternal nutrition suggest an increase in maternal anemia (often associated with iron deficiencies) in 2020-2022 because of COVID-19, ranging between 1 million to 4.8 million. This early emerging evidence suggests negative effects of COVID-19 on dietary diversity and quality.

Projecting dietary diversity and quality over multi-decadal time horizons is challenging, but we can derive important knowledge from the current analysis. In recent years, data series from UNICEF have become available on the use of Vitamin A supplements and iodine consumption. These could provide the basis for analysis on long-term drivers of micronutrient deficiencies among countries and over time. Agricultural forecasting platforms have begun to project the long-term share of meat and vegetables in global diets (van Meijl et al. 2020). In the current report we highlight the shift in consumption patterns, which show a reduction in meat consumption and an increase in crop production. These shifts don’t occur solely during the COVID-19 period. Reductions in meat consumption in Southern Asia and sub-Saharan Africa are projected to remain persistent out to 2030 and 2040 (Figure 15).

Clearly, more work is needed to be able to better project changes in long-term dietary quality and diversity, with and without COVID-19. But recent developments in data collection coupled with emerging insights from this analysis provide an opportunity to do so. These initial results strongly suggest that COVID-19 is likely to negatively affect dietary diversity and quality in the long term, relative to a world without COVID-19.

Table 5: Effect of COVID-19 on education variables among world regions in 2040. We report results among different world regions for the *No-COVID* (NC), *Current Path* (CP), and *Unequal Paths* (UP) scenarios.

Region	Education expenditures (Billion US$/ percent (%) Change)			Lower secondary completion (percent of of-age children)			Upper secondary completion (percent of of-age children)			Average years of adult education (ages 15-24)		
Scenario	**NC**	**CP**	**UP**	**NC**	**CP**	**UP**	**NC**	**CP**	**UP**	**NC**	**CP**	**UP**
Southeast Asia	229.3	-8.6%	-15.0%	90.0%	88.5%	87.5%	73.0%	71.2%	70.1%	10.4	10.3	10.3
Southern Asia	504.1	-13.2%	-21.1%	77.9%	76.2%	75.1%	63.0%	61.0%	59.7%	10.3	10.2	10.2
Oceania	123.0	0.0%	-7.8%	93.6%	93.3%	92.9%	93.8%	93.3%	92.3%	10.9	10.9	10.8
Latin America and the Caribbean	356.7	-2.6%	-14.9%	86.4%	84.9%	83.8%	72.6%	70.8%	69.5%	10.6	10.5	10.5
Middle East and North Africa	406.5	-7.0%	-13.2%	88.4%	87.2%	86.3%	72.9%	71.5%	70.4%	10.0	10.0	9.9
sub-Saharan Africa	256.3	-10.8%	-20.7%	56.2%	54.9%	53.5%	40.1%	39.0%	37.6%	8.4	8.3	8.3

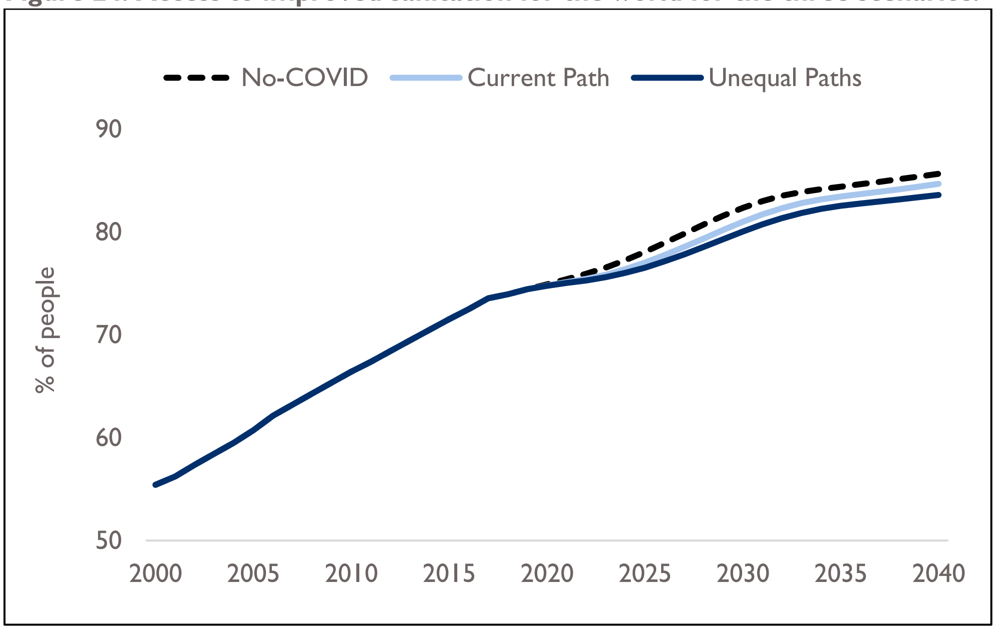
Source: Authors' calculations.

Access to improved sanitation

The population of the sub-Saharan region with access to improved sanitation is projected to increase from 33.1 percent in 2020 to 53.4 percent in 2040. However, even with such progress, the region would lag Southern Asia, where 62.5 percent of the population had access to improved sanitation in 2020.

Like COVID-19s impact on education, the impacts of the pandemic on sanitation manifest not as a sudden shock but rather as a gradual downturn in access to improved sanitation, relative to a *No-COVID* scenario. Among the world regions, sub-Saharan Africa stands out with 33.1percent of the population having access to improved sanitation in 2020, rising to 53.4 percent by 2040. This is still considerably below the level of Southern Asia in 2020 (62.5 percent in 2020).

Figure 24: Access to improved sanitation for the world for the three scenarios.

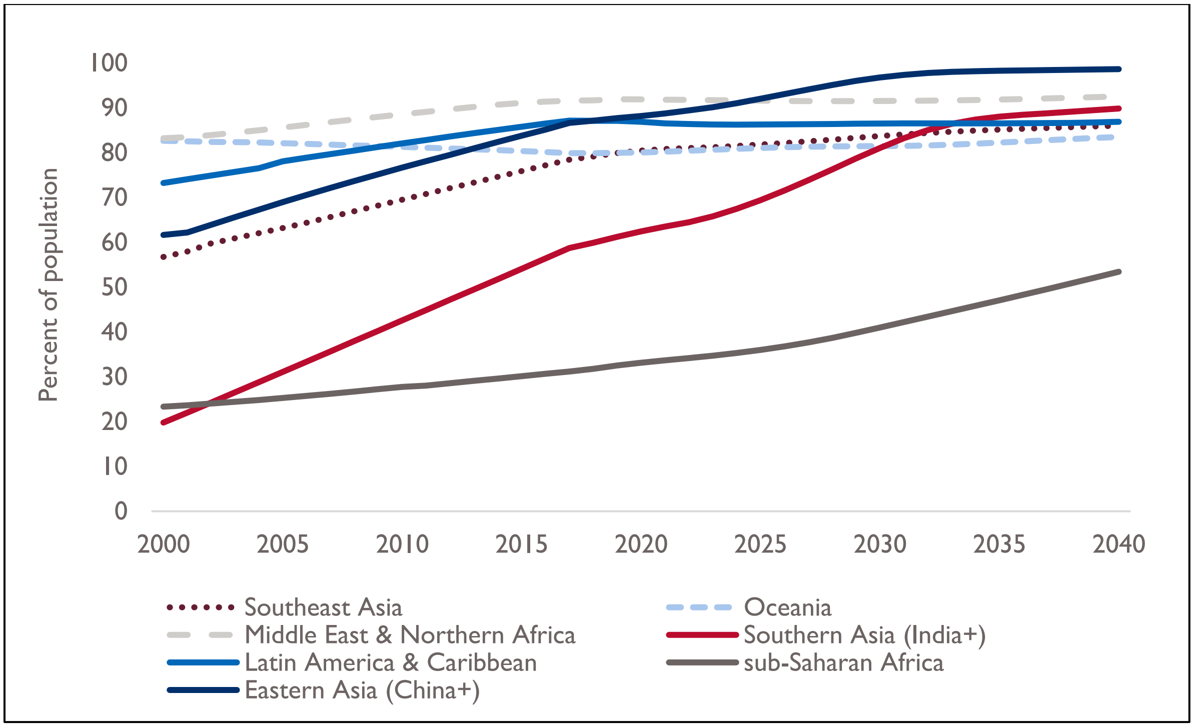


Source: Authors' calculations.

Rising government debt because of COVID-19 is projected to put additional constraints on government finances, slowing progress in access to improved sanitation, as well as reducing investment in education and a causing a general slowdown of economic growth. The world is projected to have made less progress in 2040 on these indicators, relative to a *No-COVID* scenario. The most striking effects of COVID-19 on sanitation are projected in sub-Saharan Africa, with access to sanitation in 2040 dropping by -2.5 to -6.0 percentage points relative to a *No-COVID* scenario, whereas other world regions show reductions of less than one percentage point in the *Current Path* scenario and less than 1.5 percentage points in the *Unequal Paths* scenario, relative to a *No-COVID* scenario (Figure 24). By 2040, 13 of 17 countries in which less than 50 percent of the population has access to improved sanitation are projected to be in sub-Saharan Africa (except for Papua New Guinea and some small island nations).

Table 6 gives an overview of the top 10 countries in which COVID-19 reduces access to improved sanitation. Seven are in sub-Saharan Africa and Southern Asia. The lowest percentage of people with access to improved sanitation live in sub-Saharan Africa.

Figure 25: Access to improved sanitation to 2040 among world regions under the *Current Path* scenario.



Note: Only results for region with less than 90% of the population with access to improved sanitation are depicted.
Source: Authors' calculations.

Overall, COVID-19 is affecting drivers of food utilization by lowering access to sanitation, education completion, and adult education years, as well as by lowering caloric consumption per capita. An important difference between the effects of food utilization, compared to availability and access, is that most of the impacts do not manifest directly but only over time.

These results clearly indicate that the impact of COVID-19 on human development is unlikely to cease after the virus has been contained. Moreover, these results also provide directions for policy development to reduce the effect of COVID-19 on food utilization and child stunting, and, more importantly, to reduce overall child stunting. Countries in sub-Saharan Africa are faced with a combination of challenges to improving education, access to WATSAN, and caloric demand. But the slow onset of some of these effects on food utilization means that time is still available to improve progress on these indicators and to minimize the effects of COVID-19 on food utilization.

Table 6: Effect of COVID-19 on access to improved sanitation by 2040.

Indicator	Access to improved sanitation in 2040 (percent of population)		Access to improved sanitation in 2040 (millions of people)
Country	**NC**	**CP**	**COVID-19 Effect (Absolute difference)**
Ethiopia	54.0%	49.4%	-8.2
India	99.3%	98.8%	-7.8
China	99.0%	98.7%	-5.1
Mozambique	75.0%	65.0%	-5.0
Nigeria	53.2%	52.1%	-3.8
Pakistan	66.4%	65.2%	-3.3
Myanmar	72.9%	68.4%	-2.9
Yemen	72.0%	64.9%	-2.7
Venezuela, Bolivarian Republic	77.3%	68.9%	-2.7
Madagascar	35.7%	29.8%	-2.4

Note: The table provides an overview of the ten most affected countries in absolute numbers. However, note that nearly 100 percent of the population in India and China is projected to have access to improved sanitation in 2040, far greater than in countries in sub-Saharan Africa.
Source: Authors' calculations.

6. Contextualizing COVID-19 relative to other long-term risks to food security

COVID-19 will affect food security indicators, not only today but in the future. Our analysis projects that, in 2040, COVID-19 increases extreme poverty, prevalence of undernourishment, and child stunting, relative to a world without the pandemic. While these impacts are significant, it may be difficult for readers to contextualize the impact of COVID-19 on food security. To begin to provide context, we analyze two other well-known risk factors related to the future of food security: conflict and climate change. Here we survey literature to understand the pathways whereby climate change and conflict are likely to affect food security. Next, we explore likely pathways forward for future climate and conflict trends to assess the relative magnitude and character of their impact on the future of food security.

6.1 Climate change as a driver of food insecurity

Climate change will directly and indirectly impact all three pillars of food security: supply, accessibility, and utilization. Most literature focuses on the supply and access dimension of food security, while studies linking climate change with utilization are more limited. Our review highlights the following general findings on the relationship between climate change and food security:

Climate change

Climate change will impact all pillars of food security, directly or indirectly.

- Food availability is threatened by projected reductions in yields and land suitable for agriculture for major crops. However, while the food availability pathway has received most attention within the literature, uncertainty associated with CO_2-fertilization remains large and could result in potential increases in food production from climate change, especially in particular countries or regions, compared to a scenario without climate change.
- Climate-induced effects on food availability and household income stem from both long-term reductions in agricultural production and weather volatility that can disrupt production.
- Climate change risks increasing disease spread and food-borne diseases, further challenging development in food utilization.
- Climate change does not have a distribution neutral effect on food security but is likely to have the most pronounced effects on food availability, access, and utilization in today's most food insecure regions of the world.

6.1.1 Climate change and food availability

Climate change is likely to adversely impact global food production, though this relationship is uncertain due to a lack of consensus regarding the role of CO_2-fertilization (Janssens et al. 2020a; Liu et al. 2016; Tai, Martin, and Heald 2014; Zhao et al. 2017). Rising temperatures, changing precipitation patterns, and extreme weather events threaten suitable growing conditions, particularly in the poorest, most food insecure regions of the world. For example, Tai et al. (2014) project climate change will reduce global crop yields (for wheat, rice, maize, and soybeans) in 2050 by more than 10 percent. Climate change, as well as factors like inadequate agricultural practices, deforestation, and man-made land degradation may reduce suitable agricultural land and consequently crop production. The impacts of climate change on land vary considerably among regions (Janssens et al. 2020a; Anderson, Bayer, and Edwards 2020). Temperate latitudes may benefit from warming temperatures with longer growing seasons. Lower latitudes, where the majority of developing countries are located, show the greatest decline in suitable cropland and agricultural productivity as the climate changes (Kogo, Kumar, and Koech 2021; Rosenzweig et al. 2014; Anderson, Bayer, and Edwards 2020).

Analytical insight

The impact of climate change on global food production is difficult to estimate until consensus is reached related to the role of CO_2-fertilization and its consideration in food production analysis.

However, the effects of climate change on crop production depend significantly on whether researchers account for CO_2 -fertilization. The CO_2-fertilization effect suggests that an increase in atmospheric CO_2-concentrations may promote water use efficiency and stimulate photosynthesis for C3 crops (wheat, rice, and soybean) possibly leading to an increase in food production under climate change. However, considerable debate still exists regarding the impact of CO_2-fertilization over time and among crop types (Hasegawa et al., 2018; Mcgrath and Lobell, 2013). This uncertainty is important, with studies suggesting that climate change, along with CO_2-fertilization, could increase crop production and reduce undernourishment (Baldos and Hertel 2015).

Climate change doesn't just impact agricultural production over time but also the year-to-year volatility of production. Extreme weather events, particularly droughts and flooding, threaten short-term food supplies, compounding the risk of food insecurity in the poorest and most food insecure regions of the world (Anderson, Bayer, and Edwards 2020; FAO et al. 2020; Janssens et al. 2020a; Kogo, Kumar, and Koech 2021). The sensitivity to temperature extremes varies among crops and world regions. Maize yields, for example, show strong variation with temperature extremes (Tai, Martin, and Heald 2014). Local to regional losses in food production can potentially be offset by agricultural trade, maintaining overall food availability. However, climate- and non-climate-induced food losses often come with rising food prices and reduced household income from agriculture, resulting in indirect effects of changes in food availability to economic access and rising food insecurity.

6.1.2 Climate change and food access

Climate change affects economic food access by changing patterns of economic growth, food prices, and distribution of income. Nordhaus (2018) estimates a 2.1 percent loss of global income with a 3-degree Celsius rise in global temperature and an 8.5 percent loss of global income with 6-degree rise, assuming limited changes in climate mitigation policies.

These effects operate through the agricultural economy and more broadly through impacts on labor productivity (Kjellstrom et al. 2009). These effects are expected to be most pronounced in developing countries, where a majority of the population relies on agriculture for income (Fischer et al. 2002; Nelson et al. 2010; Schmidhuber and Tubiello 2007). On average, agriculture in low-income countries constitutes 22 percent of total gross domestic product (GDP), compared to only 1 percent in high-income countries (World Bank 2019). As discussed earlier, many of these regions are at the greatest risk globally of climate-induced production losses and environmental threats (drought, land degradation).

Climate change and food access

Climate change affects economic food access by changing patterns of economic growth, food prices, and distribution of income. These effects are expected to be most pronounced in developing countries where most of the population relies on agriculture for income.

Climate change will affect overall economic growth as well as the distribution of income within these regions. Globally, more people live in poverty in rural than in urban areas. They often have limited access to markets, rely on subsistence farming, and have household incomes that are at least partly dependent on agriculture. Climate-induced shocks can reduce food access for this group by simultaneously reducing food availability and decreasing household incomes, even as food prices rise. To further underscore this point, researchers have compared climate change scenarios with negative effects on agricultural production to scenarios with climate mitigation measures lowering negative effects on agricultural production but raising food prices from mitigation measures (Hasegawa, Fujimori, Shin, et al. 2015; Hasegawa et al. 2018). They have projected that climate change may increase undernourishment by 2050, but that climate mitigation scenarios may increase undernourishment more. Thus, the causal pathway linking climate change to food access and undernourishment is closely tied to changes in household income, food prices, and poverty trends. Climate change is expected to affect household income across the entire population, but communities dependent on agriculture will be affected simultaneously by changes in agricultural production and by changes in food prices.

6.1.3 Climate change and food utilization

The last dimension of food security, utilization, is expected to increase the incidence of water- and food-borne illness alongside rising temperatures. A growing body of research indicates that higher temperatures associated with climate change raise the risk of diarrheal disease, malaria, and cholera in regions with insufficient sanitation and water management systems (Ebi 2008; Kolstad and Johansson 2011; Schmidhuber and Tubiello 2007). For example, in 2030, climate change could lead to a three percent increase in diarrheal cases and a five percent increase in malaria cases (Ebi 2008). As climatic conditions shift, there will also be changes in length of the transmission season and the geographic scope of malaria. Ryan et al. 2020 project that under the most extreme climate scenario, the Representative Concentration Pathway (RCP) 8.5, in 2080 an additional 75.9 million people will be at risk of endemic transmission in Eastern and Southern Africa. On the other hand, temperatures in large areas of Western Africa will likely exceed the thermal tolerance of malaria-carrying mosquitoes, reducing the number of people at risk of malaria by up to 120 million in 2080. This highlights the importance of anticipatory responses to shifting disease vectors under climate change (Ryan, Lippi, and Zermoglio 2020).

In addition, rising daily temperatures may increase the risk of food poisoning and food-borne pathogens (Hellberg and Chu 2015; Intergovernmental Panel on Climate Change 2007; Mbow et al. 2019). All of these factors hinder a population's ability to safely and effectively use their food (Schmidhuber and Tubiello 2007). As with the other two dimensions of food security (supply and accessibility), these effects are most salient in the poorest areas of the world, highlighting the importance of regionally concentrated mitigation strategies (Schmidhuber and Tubiello 2007).

6.2 Overview of conflict as a driver of food insecurity

Conflict and food security

Both the threat of conflict and actual conflict onset changes food availability and food utilization, with farmers shifting crop and livestock portfolios to lower risk crops and animals.

Whereas much climate change literature is based on scenarios and forward-looking analysis, the literature on conflict and food security is based primarily on historical examples. These case studies provide valuable insight into how conflict impacts food availability, access, and utilization. Studies projecting future conflict-induced food insecurity are scarce, and most projections rely on theoretical links, with only a few quantifying the impact of future conflict on food insecurity. Overall, the pathways review finds that:

- Both the threat of conflict and actual conflict onset change food availability and food utilization, with farmers shifting crop and livestock portfolios to lower risk crops and animals.
- Conflict reduces agricultural production and trade, raising the risk of acute food shortages.

- Conflict affects both physical and economic food access, with disproportionate impact on children and women. Physical access is reduced when infrastructure is destroyed and deliberate restrictions on access to food are employed as weapons of war.
- Conflict affects food utilization by increasing the spread of diseases, crowding and unhygienic conditions in emergency camps, limiting access to healthcare, and destroying infrastructure.
- Long-term effects of conflict operate through reduced economic growth, reduced GDP per capita, and a reduction and reallocation of government finances.
- Conflict also disproportionately impacts children, with increases in all forms of child malnutrition. Moreover, children are affected by education losses and are particularly vulnerable to the spread of disease. These effects are often not limited to the duration of the conflict.
- Displaced populations are another group disproportionately affected by conflict who experience acute food insecurity and longer-term impacts on agricultural production and economic welfare, relative to non-displaced populations.

6.2.1 Conflict and food availability

Overall, data shows that conflict negatively affects food availability during ongoing hostilities and continues even after hostilities stop. The threat of conflict can be enough to negatively affect food availability. Before a conflict occurs, the threat of violence can change crop and livestock portfolios (Rockmore 2015). A study off 690,000 households in Uganda found that farmers living under the threat of violence tended to shift to low-risk seasonal crops. Crops like fruits and vegetables, which have short harvest times and can be easily looted, decreased significantly, and large grazing animals were traded for small livestock (Rockmore 2015). These shifts contribute to a decrease in crop diversity and nutritional availability even under just the threat of conflict.

During a conflict, food sieges, looting, theft, and violence can decimate local crop yields (Martin-Shields and Stojetz 2019; Messer, Cohen, and D'Costa 1998; Messer and Cohen 2015). Farming populations are reduced through active participation in the conflict, through attacks and enslavement, or through forced migration, abandoning the land. Another way in which conflict reduces food availability is by affecting agricultural imports. Conflict can result in border closures, while airports and seaports are often strategic locations for attacks, greatly diminishing the necessary infrastructure for distributing agricultural products. This is especially impactful in food-import-dependent countries, as currently shown by the food crisis in Yemen (Moyer, Bohl, et al. 2019).

Because of reductions in labor, human capital, reduced investment, unraveling of local to national institutions, and damage to infrastructure, the long-lasting effects of conflict on agricultural production continue even after conflict ceases. This is especially true for populations directly impacted by violence. For example, in Burundi, caloric intake among the population forced to flee violence decreased by six percent over that of the non-displaced population after the Burundian civil war (Verwimp and Muñoz-Mora 2013). Ultimately, the effects of conflict on agriculture are not confined to the beginning and end of a war, stressing the devastating potential of even short-term conflicts on food availability.

6.2.2 Conflict and food access

Conflict impacts the physical and economic dimensions of food access, with the most pronounced effects on women and children (Ayala and Meier 2017; Ibañez and Moya 2010; United Nations Security Council. 2002). Civilians are unable to compete with "men with guns" and armed forces can deprive women and children of food even when resources are abundant (Messer and Cohen 2015). Market and transport systems are destroyed in conflict, isolating conflict zones from physical food supplies and aid and challenging the physical access to food (Messer and Cohen 2015). Specific targeting of food production and food aid shows that food insecurity can be used "as a weapon of war," with civilians, mainly women and children, often the target (Chen et al. 1990; Cousin 2016; Teodosijevic 2003; United Nations Human Rights Council 2020).

Insights from the literature: differentiated impacts of conflict

Conflict affects both physical and economic food access, with a disproportionate impact on children and women.

The economic consequences of conflict also contribute to worsening poverty levels and related constraints on food access. Conflict-affected countries experience downturns in GDP per capita and government resources tend to be allocated to the military rather than to on social services (Gates et al. 2012a). Reduced spending on education, health, and infrastructure leads to a decline in socioeconomic development and higher levels of poverty. Interestingly, this effect is irrespective of the duration of the conflict. The direct aftermath of short-term wars tend to be reduced GDP, due to the negative effect on the investment climate and growth in military expenditures, whereas long-term wars tend to be followed by a period of rapid economic growth insufficient to recover previous losses (Gates et al. 2012a).

Once again, these negative effects tend to be most concentrated among women and children. Child malnutrition, wasting, and stunting tend to be strongly affected by conflict, and rising levels of child malnutrition today can have long-term effects on cognitive and physical development. As men participate in armed conflict, women are expected to provide food for their households. However, women often lack property rights and financial independence, restricting their economic access to food during wartime (Ayala and Meier 2017, 7). Women and children also constitute the majority of refugees. In fact, in Yemen, more than three-quarters of the displaced population are women and children (Moyer, Hanna, et al. 2019). Moyer et al., projected in 2019 that if conflict in Yemen continues, the country will rank last on the gender development index (GDI) of any country in the world by 2030. Among displaced populations, the loss of assets, income, and education contributes to an increase in long-term poverty (Ibañez and Moya 2010). Accordingly, Verwimp and Munoz Mora (2013) found that it takes eight to ten years for welfare and economic levels of displaced persons to reach the level of the non-displaced community, contributing to higher poverty levels and lower caloric intake for years after a conflict.

6.2.3 Conflict and food utilization

Conflict also interferes with food utilization, creating long-term public health crises. Worsening dietary diversity and nutritional availability negatively impacts food utilization during and after a conflict. As described by Rockmore (2015), the threat of conflict results in a shift to low-risk crops, worsening the availability of micronutrients and proteins. Dietary diversity in conflict zones and emergency camps also diminishes during war, one mechanism by which conflict increases the incidence of malnutrition (Dabalen and Paul 2012; Messer, Cohen, and D'Costa 1998). Interviews with key informants in the refugee context in Kenya revealed that livelihoods and refugee training programs requiring daily attendance over few hours typically provided "high carbohydrate foods- such as baked goods, tea, and/or soft drinks," which often lack adequate protein and nutrients needed for supporting engagement, attention, and general performance (RTAC and USAID 2020, 5). Additionally, the destruction of public health systems as well as unhygienic conditions in emergency camps can worsen food utilization, perpetuating a cycle of nutritional deprivation and disease (Messer, Cohen, and D'Costa 1998; Messer and Cohen 2015).

Malnutrition and stress in emergency camps compromise the immune systems of people living in them. At the same time, epidemic diseases are more likely to spread as a result of "crowding, bad water, and poor sanitation in camps" (Ghobarah, Huth, and Russett 2003, 192). Epidemiological research in conflict regions shows higher mortality rates from disease than combat (Degomme and Guha-Sapir 2010; Gates et al. 2012a). Yip and Sharp (1993) found that 12 percent of Kurdish refugee infants died during the first two months of the Kurdish refugee crisis of 1991 due to diarrhea, dehydration, and subsequent malnutrition.

Nutritional deprivation and disease from conflict has long-lasting consequences on health outcomes. In a study of the effects of the Nigerian Civil War of 1967 to 1970, Akresh et al. (2012) found that exposure to conflict during early childhood and adolescence had an impact on adult stature four decades after the conflict came to an end. The effects were most pronounced for women exposed to conflict during adolescence (13–16 years old). On average, this group is 4.54 cm shorter in stature than non-exposed women of the same age (Akresh et al. 2012). A study of the effects on Peruvian populations of the Shining Path guerrilla war of the 1980s and 1990s found that exposure to conflict even in utero led to shorter stature after birth and later in life (Grimard and Laszlo 2014). Malnutrition during wartime may have other, less visible, consequences. In a study of the long-term effects of the U.S. war in Vietnam, Singhal finds a correlation between early-life exposure to war and mental health problems later in life. The study suggests that malnutrition during wartime is a significant mechanism contributing to long-term impacts on mental health (Singhal 2019).

Other long-term effects of conflict on food utilization can materialize through reduced education and access to WATSAN. Conflict can result in physical damage to infrastructure, including roads, bridges, schools, and water and sanitation infrastructure, leading to reduced access to education and WATSAN during and after a conflict. Education losses tend to be persistent over time. Conflict and reduced economic growth tend to affect government finances, resulting in both an overall reduction and a reallocation of resources. Lai and Thyne (2007) found that conflict-affected countries reduce their education expenditures 3.1 to 3.6 percent. However, another cross-country study on conflict and social development goals did not find a statistically significant effect of conflict on education, though it did find a significant downturn in access to potable water and an associated higher level of child mortality (Gates et al. 2012a). Reduced economic growth, higher levels of undernourishment and child stunting, a change to economic structures affecting long-term human development, and changes in government finances can reduce investments in education and WATSAN. Once again, literature on conflict and food utilization highlights not only the direct negative effects of conflict, but also the threat conflict poses to long-term achievement of sustainable development goals.

6.3 The conflict-climate-food security nexus

Food security, conflict, and climate change interact in dynamic ways, and separating individual effects without acknowledging the feedback loops between these systems provides only a partial perspective. In recent years, researchers have begun to study the nexus of climate, conflict, and food security, with increasing focus on climate change and climate-induced food insecurity as a potential driver of conflict. Results of these studies vary considerably, and it is difficult to draw firm conclusions of a causal link between climate change and conflict across regions and contexts (Bernauer, Böhmelt, and Koubi 2012; Gleditsch 2012; Koubi 2019).

Conflict-climate-food security nexus

Food security, conflict, and climate change interact in dynamic ways, and separating individual effects without acknowledging the feedback loops between these systems only provides a partial perspective. There is a general consensus, however, that climate change will amplify conflict risk in regions, with some existing risk factors including high agricultural dependency, low levels of economic development, and evidence of political marginalization.

There is a general consensus, however, that climate change will amplify conflict risk in regions, with some existing risk factors including high agricultural dependency, low levels of economic development, and evidence of political marginalization (Koubi 2019; Raleigh 2010; Buhaug, Gleditsch, and Magnus 2008; Bernauer, Böhmelt, and Koubi 2012). Several large-scale empirical studies have attempted to capture the effects of long-term climate change by analyzing the impact of mean temperature changes on conflict (Burke et al., 2015; Burke et al., 2009; Hsiang et al., 2013). Burke et al., 2015 studied deviations from moderate climate patterns (temperature and precipitation) using a hierarchal meta-analysis of 55 studies. The study found a statistically significant positive correlation between climate variability and conflict risk. Similarly, Burke et al. (2009) quantifies conflict risk in Africa by combining data on historical responses to temperature with climate models of future temperature trends. The results suggest Africa could see a 54 percent increase in the likelihood of armed conflict by 2030, relative to a future without climate change and conflict.

However, the literature generally warns against overstating the impact and causality on conflict of climate change and the environment. While climate change may exacerbate human conflict risks, relative to a world without climate change, this does not occur in isolation (Bernauer, Böhmelt, and Koubi 2012; 2012; Buhaug, Gleditsch, and Magnus 2008; M. B. Burke et al. 2009; Raleigh 2010; Raleigh and Urdal 2007; Salehyan 2008). Raleigh (2010) and Ide et al. (2014) examined conflict incidence in Africa and determined that environmental issues can exacerbate violent conflict risk. However, the most important factors are the extent of political and economic marginalization (Raleigh 2010) and the degree of poverty and agricultural dependence (Ide et al. 2014). Accordingly, many researchers have adopted a multicausal approach to project environmental-induced conflict (Busby 2017; Moran et al. 2018; Raleigh 2010). Here we have studied conflict and climate change in isolation, and the next section will aim to quantify separate effects. However, while evaluating these sections it is important to remember that interactions between climate-conflict-food security generally may occur. More importantly, regions with the highest levels of food insecurity, including sub-Saharan Africa and parts of Southeast Asia, are also at the highest risk of environmental-induced conflict (Moran et al. 2018). Compounding climate and conflict threats on food insecurity show the importance of concentrated mitigation efforts in some of the worlds' most impoverished regions.

6.4 Projecting the future of climate change and conflict.

To this point, this report has assessed the impact of various disruptive trends on food security. A direct comparison across these alternative risk factors remains difficult to summarize. To contextualize the impact of these drivers on food security it is necessary to review our understanding of how we expect these factors to unfold over time. Here we provide an overview of estimates from literature, specifically focusing on studies that provide long-term projections.

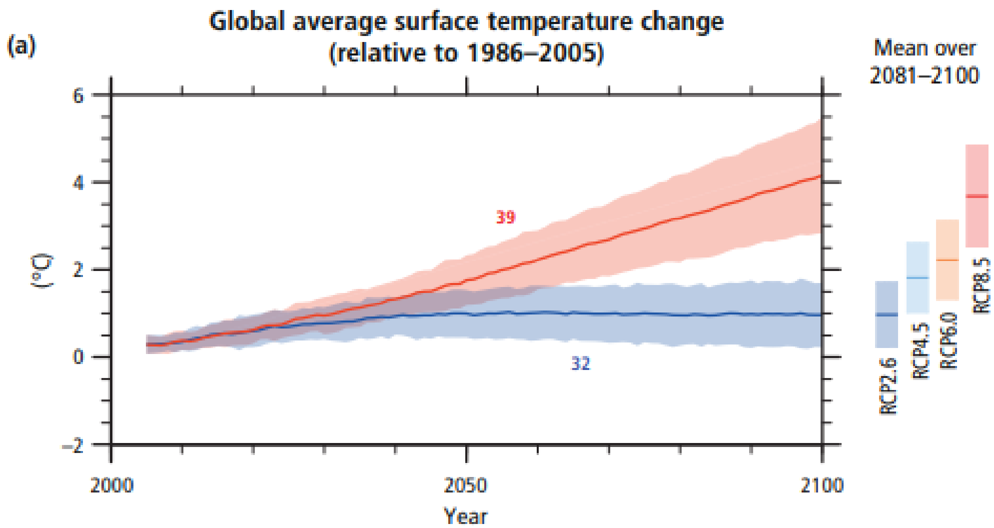
We begin by outlining how different studies have presented the future of climate change and conflict, highlighting the significant bounds of uncertainty and drivers relevant for each. We use the three outcome indicators studied previously to compare the different pathways whereby conflict, climate change, and COVID-19 affect development, undernourishment, child stunting, and extreme poverty.

6.4.1 The future of climate change

A standardized approach to forecasting climate change uses RCP, a greenhouse gas concentration trajectory adopted by the Intergovernmental Panel on Climate Change (van Vuuren et al. 2011). These alternative scenarios describe climate change futures with radiative forcing varying from 2.6 to 8.5 W/m^2 through the year 2100. These radiative forcing levels stem from alternative emission futures from industry and land use, with RCP 2.6 accounting for extensive mitigation measures. These RCP scenarios represent a consecutive increase in emissions and climate change out to 2100, with RCP 6.0 having more climate change effects than RCP 4.5. However, most climate to food security studies focus on effects out to 2050. By 2050, the different emission pathways followed by the RCPs represent a different ranking, with—in ascending order of the extent of climate change—RCP 2.6, RCP 4.5, RCP 6.0, and RCP 8.5.

These climate change pathways are exogenously prescribed to crop growth and integrated assessment models with varying assumptions across these models on the impact of climate change on yields, land, and consequently, food security. As such these climate change projections primarily focus on the biophysical, food availability aspects of climate change to food security, although in recent years more attention has been given to the forward effects on food prices and dimensions of food access. A crucial assumption to assess the climate to food security effect across these models is whether the study accounts for CO_2-fertilization effects. Even though the use of RCP represents a standardized approach, recent inter-model comparison efforts show that considerable uncertainty also stems from the choice of climate model, as well as the choice of crop growth or integrated assessment model to assess the forward effects of climate change on production and undernourishment (Hasegawa et al. 2018; Janssens et al. 2020a).

Figure 26: Change in global average surface temperature across different RCP scenarios, according to the IPCC 2015 assessment report (AR5).



Source: Intergovernmental Panel on Climate Change (2015). Climate Change 2014: Synthesis Report. Contribution of Working Groups I, II and III to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change.

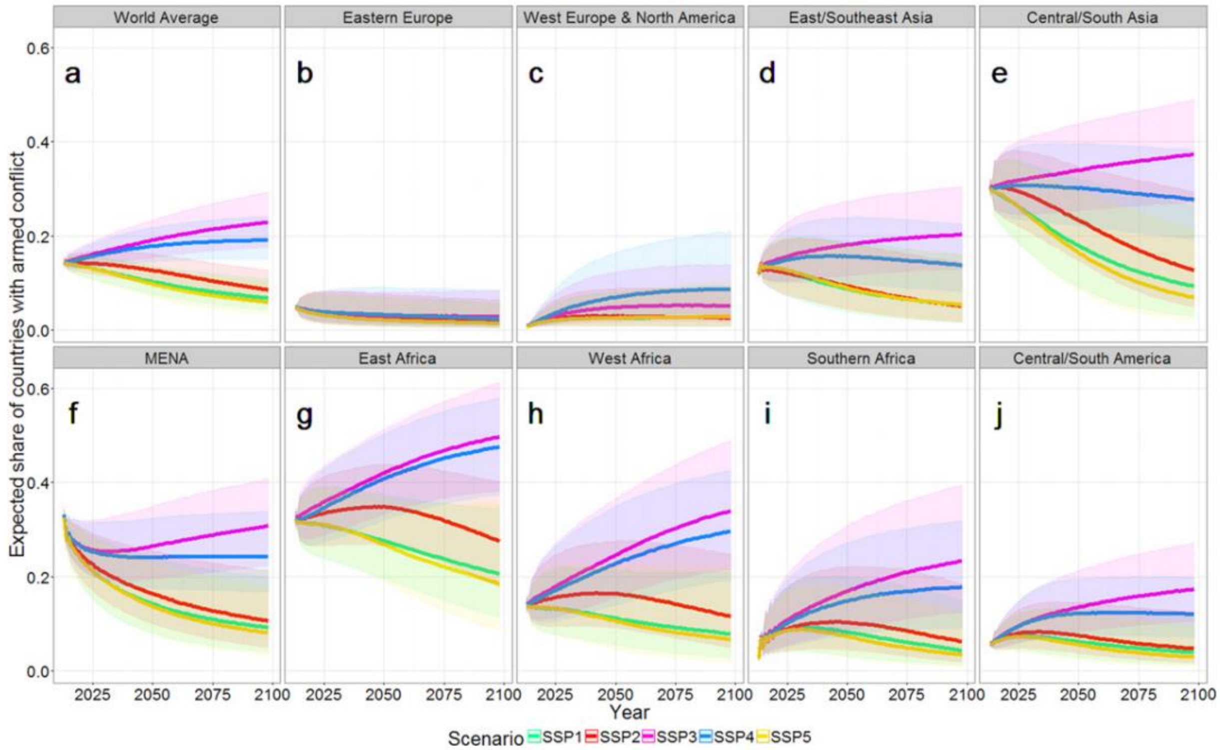
Additional uncertainty is associated with the extent of climate change. The future impact of RCP on temperature change is broad, with RCP 8.5 leading to an average change of 4 degrees centigrade by 2100 (Figure 26). RCP 2.6, on the other hand, retains average surface temperatures at their same level. The future impact of climate change, while an ongoing and real phenomenon, is characterized by deep uncertainty.

6.4.2 The future of conflict

A few key themes emerge when evaluating literature on future conflict. Historical conflict incidence and projected socioeconomic development trends are significant determinants of future conflict risk. Long-term conflict forecasts are characterized by uncertainty, making projecting conflict difficult.

Country-level history with conflict is one of the greatest drivers of future conflict. Hughes, Joshi, Moyer, Sisk, and Solórzano (2014) note a 60 percent carryover of past conflict levels to current ones, concluding that "conflict tends to beget conflict." Development trends are another frequently cited factor in conflict risk. Hegre et al. (2016) conclude that socioeconomic futures with high investment in poverty alleviation and human capital lead to greater stability, particularly in developing countries. Similarly, Joshi, Hughes, and Sisk (2015) emphasize the importance of development in achieving security, capacity, and inclusion. While the study projects that the world will generally become more peaceful in the coming decades, the implementation of pro-development policies determine the extent and scope of this stability.

Figure 27: Projected share of countries with conflict to the year 2100 for the world and world regions according to Hegre et al (2016).



Note: Individual lines depict scenarios, and shaded areas represent uncertainty intervals.
Source: (Hegre et al. 2016).

Structural pressures, including regime type and horizontal inequalities (ethnic, religious, or racial group inequality), explain why some countries may experience political instability. A significant body of literature cites horizontal inequalities and group-level discrimination as drivers of instability (Cederman, Weidmann, and Gleditsch 2011; Østby et al. 2011; F. Stewart 2005). Additionally, regime types may influence regional conflict risk. Regimes combining autocratic and democratic features and democracies with high levels of poverty are cited as particularly susceptible to conflict (Bello-Schünemann and Moyer 2018; Hughes, Joshi, Moyer, Sisk, and Solórzano 2014).

Insights from the literature: future of conflict

Very few studies exist that project conflict into the future, let alone the effects thereof on extreme poverty, undernourishment and child stunting. Historical conflict incidence and projected socioeconomic development trends are significant determinants of future conflict risk.

It is important to note that structural pressures are not inherent drivers or predictors of political instability. Regions that appear to have similar risk factors on the surface may diverge and experience vastly different futures. Development, inequality, and governance dimensions interact in complex ways and vary considerably across regions, making it difficult to determine a unified set of indicators (Bello-Schünemann and Moyer 2018). Thus it is difficult to predict conflict, and current forecasts are characterized by uncertainty (Bowlsby et al. 2020).

The future distribution of internal conflict shows significant uncertainty with much regional differentiation. Hegre et al. (2016) project that regions such as East Africa, West Africa, Middle East and North Africa, and Central/South Asia are likely to experience the widest range of uncertainty through the end of the century, with some scenarios driving up conflict considerably and other scenarios reducing the likelihood of conflict (Figure 27). Other regions show persistently greater low levels of conflict, like Eastern Europe. The future distribution of conflict is also characterized by uncertainty.

6.5 Linking climate change and conflict to outcome indicators

Throughout this report we have used three outcome indicators to better understand the effect of COVID-19 on food security: levels of undernutrition, stunting, and poverty. This reflects an understanding of food security that cuts across different dimensions of development and focuses primarily on the impact on the most vulnerable populations. In this section, we explore how climate change and conflict are likely to impact these areas as well. While a direct comparison of each risk factor's contribution to various outcome indicators is not possible, general themes emerge.

6.5.1 Climate change to poverty

There is a consensus that climate change directly and indirectly changes levels of poverty, though there are no comprehensive studies that quantify the effects. Natural disasters, agricultural disturbances, and health-related shocks—all expected to increase with climate change—increase poverty rates (Hallegatte et al. 2014; 2016; Hallegatte, Fay, and Barbier 2018; Skoufias, Rabassa, and Olivieri 2011). Hurricanes, floods, and droughts destroy assets and livelihoods, mainly those of the poor who are more vulnerable due to a lack of resources and social support (Hallegatte et al. 2016). Natural disasters also impact agriculture by destroying crops and reducing incomes for farmers, as well as by increasing food prices.

Examples from various case studies demonstrate how climate has already impacted poverty, especially in impoverished communities. One study looking at the effect of natural disasters in Central and South America found that floods and droughts had increased poverty by up to 3.7 percent in Mexico, by up to 23 percent in Peru, and by 12 percent in Bolivia (Rodriguez-Oreggia et al. 2013). In Ethiopia, a devastating drought in 1984 reduced agricultural production, causing a large-scale famine. Asset-poor households took an average of 10 years just to restore their holdings to pre-famine standards (Hallegatte et al. 2016). In Mumbai, regular floods contaminate drinking water, reduce food availability, and increase disease. In a survey of 200 households located in the flood zones of Mumbai, 40 percent reported instances of diarrhea, 64 percent report cases of malaria, and 86 percent report cases of viral fever because of increasing floods. Cases of malaria increased by 217 percent from 2001 to 2011 as a direct result of the accumulation of water from intensified monsoon seasons coupled with poor sanitation in low-income areas (Hallegatte et al. 2016). When examining macro-level impacts of climate change on poverty, a Nordhaus (2017) study estimates that a 3 degrees Celsius increase in global temperature can lead to a 2.1 percent decrease in global income, with associated effects on poverty.

6.5.2 Climate change to undernourishment

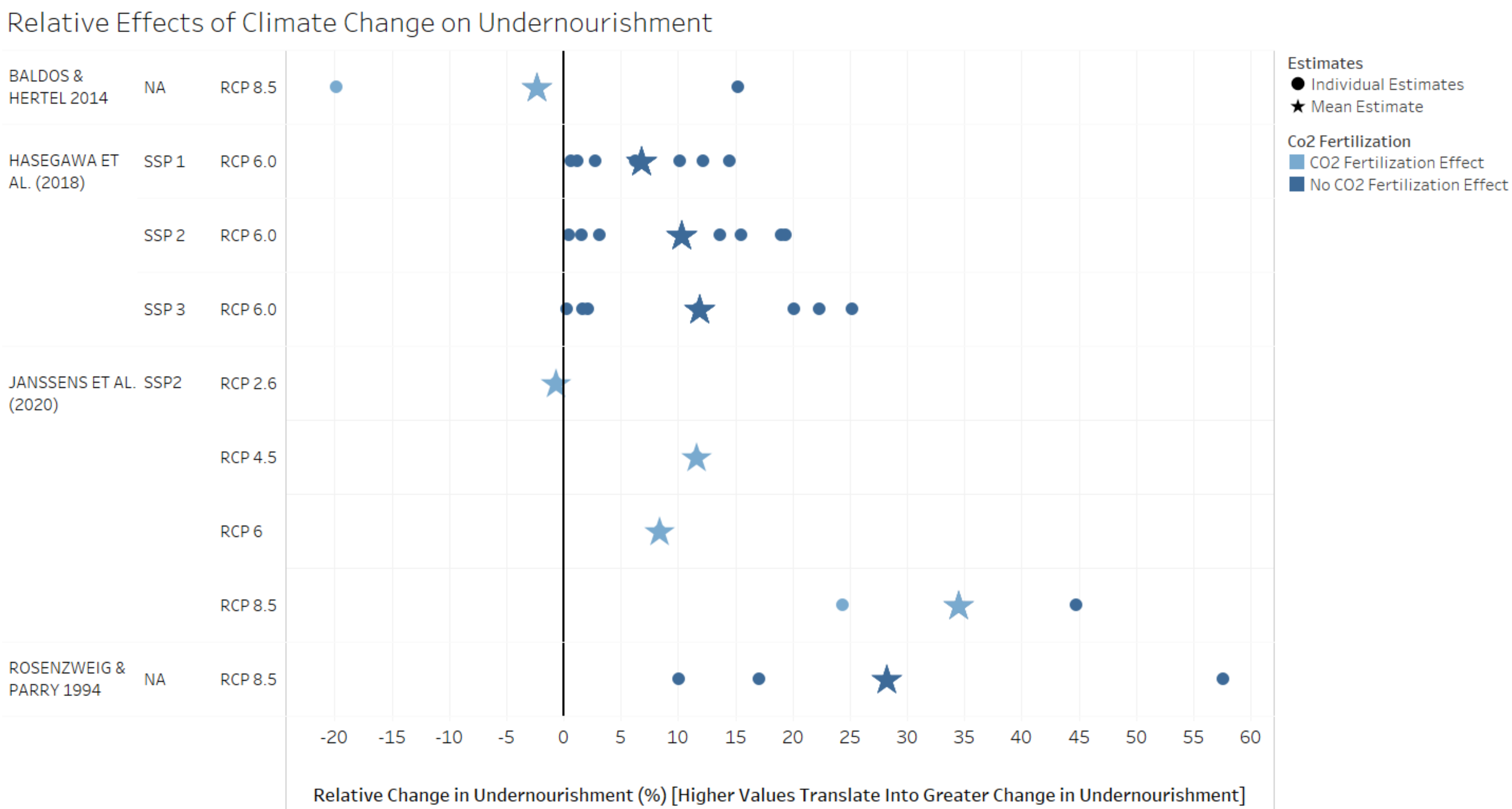
There have been several global long-term forecasting studies that project the effect of climate change on undernourishment out to 2050. These studies generally use consistent approaches, with the use of RCP against a *no-climate change* scenario. This allows for direct quantification of climate change on undernourishment, as the percentage increase in the number of people in undernourishment relative to a no-climate change future.

The magnitude of this effect varies among studies, from -2.29 percent to 34.56 percent change in the population suffering from undernourishment relative to a *no-climate change* baseline scenario (Figure 28). Improvements in undernourishment because of climate change generally incorporate a CO_2-fertilization effect, whereas all studies that do not account for CO_2 fertilization project an increase in undernourishment from climate change. Within a single study, more climate change results in an increase in undernourishment, with projections from Janssens et al. (2020) varying between a -0.6 percent decrease in undernourishment with strong mitigation efforts and limited climate change (RCP 2.6) and a 24.4 percent increase with high climate change (RCP 8.5). The effect of COVID-19 is projected to vary between a 6.2 percent to 12.0 percent increase in undernourishment by 2040, very much within the range of uncertainty of climate change estimates. However, an important distinction is that climate change effects tend to worsen further out into the century, whereas the effects of COVID-19 are likely to lessen over time.

Climate change and COVID-19

The effect of COVID-19 is projected to vary between an 6.2% to 12.0% increase in undernourishment by 2040, very much within the range of uncertainty of climate change estimates. However, an important distinction there is that climate change effects tend to worsen further out into the century, whereas effects of COVID-19 are likely to lessen over time.

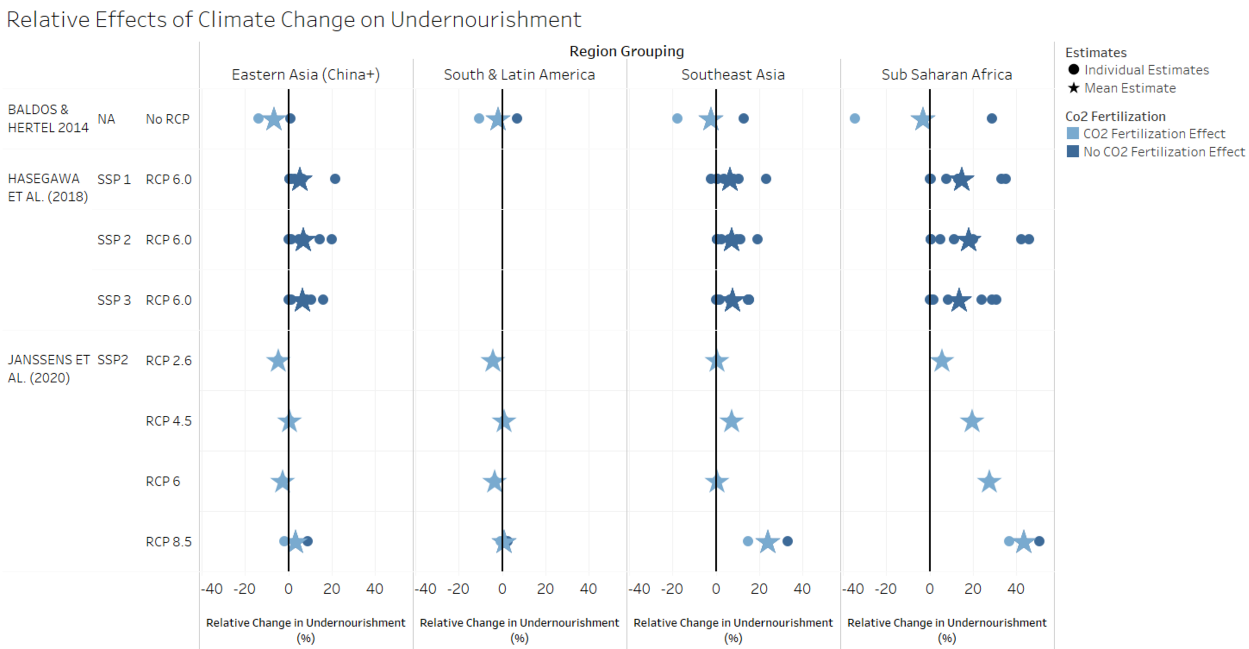
Figure 28: The relative effect of climate change on undernourishment at the global level by 2050, according to literature consulted.

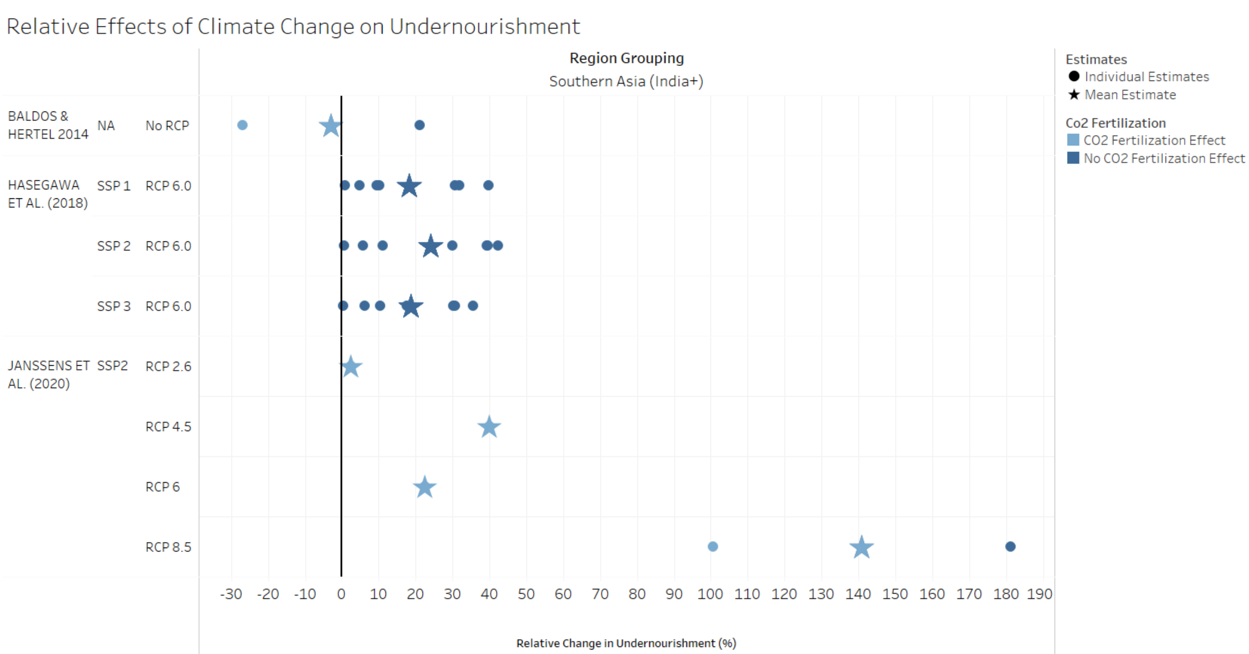


Note: The percent decrease or increase is relative to a no-climate change baseline scenario. The stars depict mean effects for studies that have multiple data points. The individual data points represent estimates using different climate or crop growth models and whether the climate to food security accounts for CO_2-fertilization (dark versus light blue). To isolate the climate effect, we break up measures in studies according to SSP and RCP. Rosenzweig and Parry (1994) use an endogenous socioeconomic scenario and a climate change scenario close to RCP 8.5. Baldos and Hertel (2005) also use an endogenous socioeconomic scenario.

Source: Authors' elaboration based on the cited literature.

Figure 29: The relative effect of climate change on undernourishment for different world regions by 2050, according to literature consulted.





Note: The percent decrease or increase is relative to a no-climate change baseline scenario. The stars depict mean effects for studies that have multiple data points. The individual data points represent estimates using different climate or crop growth models, and whether the climate to food security accounts for CO_2-fertilization (dark versus light blue). To isolate the climate effect, we break up measures in studies according to SSP and RCP. Rosenzweig and Parry (1994) use an endogenous socioeconomic scenario and a climate change scenario close to RCP 8.5. Baldos and Hertel (2005) also use an endogenous socioeconomic scenario.
Source: Authors' elaboration based on the cited literature.

The effect of climate change on undernourishment is most pronounced in sub-Saharan Africa and Southern Asia (Figure 29). As with COVID-19, climate change is projected to have the largest negative effect on undernourishment in the most food insecure regions of the world. In Southern Asia, effects vary between -2.6 percent to +40 percent, with an extreme outlier of +141 percent under severe climate change (RCP 8.5). The effect of COVID-19 in Southern Asia varies between a +7.3 percent to +13.7 percent increase in undernourishment, at the lower end of most estimates. For sub-Saharan Africa, the effect of climate change on undernourishment varies between -2.9 percent to +43.8 percent. Even with CO_2-fertilization, climate change generally negatively affects undernourishment out to 2050 (except for Baldos and Hertel, 2014), and the difference between an estimate with and without CO_2-fertilization is less pronounced. This suggests that while CO_2-fertilization is a big associated uncertainty, climate change seems to increase undernourishment in sub-Saharan Africa, with or without this assumption. Undernourishment due to COVID-19 ranges from 4.9 and 11.1 percent. Only two climate change projections report an increase in undernourishment below 11.1 percent, either with limited climate change (RCP 2.6) or strongly driven by positive effects of CO_2-fertilization. As such the effect of COVID-19 on undernourishment in sub-Saharan Africa is at the lower end of the projections.

6.5.3 Climate change to child stunting

We could find just one study projecting the effects of climate change on child stunting and highlighting the need to further integrate child stunting and aspects of food utilization into long-term projections of climate and food security. The study by Lloyd et al. (2018) projects child stunting to 2050 using the GLOBIOM model, with varying assumptions on climate change (RCP 2.6 and RCP 8.5) and socioeconomic projections (SSP4 and SSP5). However, the effect of climate change on child stunting in this study is projected to be minimal, with limited variation for the four different scenarios (+0.6 percent to +1.0 percent). The impact of COVID-19 in this study is considerably larger, with a projected increase of 4.0 percent to 7.7 percent by 2040. It would be premature to base any definitive comparative conclusions on such a limited base of evidence. However, one important consideration is that child stunting tends to be driven by many socioeconomic conditions, such as overall economic growth, parental education, and access to WATSAN, all of which are more directly affected by COVID-19 then by climate change.

One important omission is that climate change studies generally focus on mean reductions in crop production and less on volatility in production. Wasting in children tends to be much more responsive to immediate reductions in food, from extreme weather events or conflict (Moyer et al. 2020). However, wasting and stunting generally share the same drivers, and early childhood wasting tends to make children more susceptible to stunting in the following months to year (Li et al. 2020; Briend, Khara, and Dolan 2015; Blankenship et al. 2020). Thus, the dominant pathway of climate change to child stunting may operate through climate-induced shocks, but this is currently an omission in our understanding of how climate change may affect food security and child stunting in the future.

Analytical insight

Projections of the effects of climate change on child stunting and extreme poverty are largely absent, making a quantitative comparison between effects of climate change and COVID-19 difficult for these indicators.

6.5.4 Conflict to poverty

Conflict has a significant and negative impact on poverty incidence, both during and after conflict. Conflict increases levels of poverty by destroying assets and diverting public funds from social programs (Bircan, Bruck, and Vothknecht 2010; Justino 2012; Marks 2016; Rohwerder 2014). The destruction of assets during periods of conflict inhibits people's participation in the market, which reduces overall economic productivity (Justino 2012). As a result, conflict correlates with reductions in GDP per capita and GDP growth (H. Mueller and Techasunthornwat 2020). In addition, conflict increases government expenditure on the military, which diminishes resources for social programs (Gates et al. 2012a; Rohwerder 2014). People living in poor conditions already depend heavily on social services; a reduction in government assistance can further worsen living conditions or even push people further into poverty (Bircan, Bruck, and Vothknecht 2010).

The study of historical conflict supports this. During the Rwandan genocide in 1994 people's assets were destroyed or stolen, leaving them with no livelihoods or access to the market. If the conflict had not taken place, Rwandan GDP per capita would be as much as 30 percent higher, which could have reduced poverty up to 15 percent (World Bank 2004). The civil war taking place in Yemen has destroyed infrastructure, capital, and personal assets (including land and livestock) while displacing millions (Moyer, Hanna, et al. 2019; Moyer, Bohl, et al. 2019). Loss of assets and of income have resulted in widespread poverty. If the conflict continues, it is estimated that by 2030, as much as 80 percent of the population may live in extreme poverty (Moyer, Hanna, et al. 2019).

While short-term effects of conflict on poverty are understood to be severe, longer-term effects appear to be more muted. At the macro-level, post-conflict states may recover lost assets or damaged capital (Justino 2012). However, long-term effects may be more prevalent at the individual level due to the loss of education and, in turn, economic mobility and general livelihoods (Justino 2012). Women and children also constitute the majority of refugees displaced by conflict situations. Among displaced populations, the loss of assets, income, and education contributes to an increase in long-term poverty levels (Ibañez and Moya 2010). Accordingly, Verwimp and Muñoz-Mora (2013) found that it takes 8 to 10 years for welfare and economic levels of displaced persons to reach the level of the non-displaced community, contributing to higher poverty levels and lower caloric intake for years after a conflict. While more muted, negative impacts on poverty reduction in a post-conflict context seem to be greater compared with a counterfactual world in which conflict did not exist.

6.5.5 Conflict to undernourishment

The literature on conflict as a driver of undernourishment is generally historically focused and uses a wide range of methodologies, indicators to assess the effect, and spatial and temporal scales. That makes a one-to-one comparison nearly impossible. Therefore, we present a descriptive overview of quantitative effects (Table 7).

Several studies have examined the effect of conflict on food production. Messer et al. (1998) examined food production in the war-torn countries of sub-Saharan Africa from 1970 to 1994. The study found that food production per capita dropped by a mean of 12.3 percent in war years compared to peace times. Similarly, in an analysis of 38 countries, Teodosijevic (2003) found that agricultural production dropped by about 1.5 percent per year during times of conflict, and mean caloric intake dropped by seven percent.

Only a single study looked at the effect of conflict on the number of people in undernourishment. A cross-national assessment by Gates et al. (2012) found that medium-sized conflict resulting in approximately 2,500 battle deaths led to a 3.3 percent increase in the number of undernourished.

There have been very few studies of the effects of continued conflict over a prolonged period. In one, a study on the duration of conflict in Yemen on human development using the IFs model suggests that a prolonged conflict out to 2030 could result in 95.5 percent of the population in Yemen suffering from undernourishment in 2030, relative to 27.3 percent in 2030 if the conflict were to end by 2022 (Moyer, Hanna, et al. 2019). This range of conflict effects on undernourishment highlights potential severe prolonged effects. But it also cautions against an overly simplistic direct comparison of the effects of COVID-19 on undernourishment with the effects of conflict on undernourishment, given challenges in projecting and assessing the effect of conflict on the future of food security.

What we can say is that without changes in policies, the effect of COVID-19 on undernourishment, directly and out to 2040, is significant, even when compared to direct impacts of conflict. However, explorative assessments of multi-year conflict suggest a much higher long-term impact of conflict on undernourishment. Much more work is required to model the occurrence and severity of conflict out to the future to better understand the potential range of impacts across countries and world regions.

Table 7: Overview of literature estimating an effect of conflict on indicators of undernourishment and poverty.

Source	Timeframe	Indicator	Where	Finding
Teodosijevic (2003)	During conflict	Supply—Agricultural Production	Cross-national	On average, agricultural production drops by about 1.5 percent per year during conflict
Messer et al. (2012)	During conflict	Supply—Food production per capita	Sub-Saharan Africa	Mean 12.3 percent drop in food production per capita in war years compared to peace times, for war-torn countries in sub-Saharan Africa between 1970–1974
Gates et al. (2012)	During conflict	Generic—Mean dietary energy requirement	Cross-national	Medium conflict (2,500 battle deaths) leads to a 3.3 percent increase in the population living on less than the mean dietary energy requirement
Verwimp and Mora (2013)	Post-conflict	Generic—Lower caloric intake	Burundi	The Burundian population forced to flee violence experienced 6 percent lower caloric intake than the non-displaced population after the conflict
	Post-conflict	Access—Welfare and economic levels	Burundi	It takes 8 to10 years for welfare and economic levels of displaced persons to reach the level of non-displaced community
World Bank (2004)	Post-conflict	Per capita GDP	Rwanda	Had the Rwandan Genocide not occurred, GDP per capita could be up to 30 percent higher today
Moyer et al. (2019)	During conflict	Population (percent) living below the national poverty line	Yemen	The population in Yemen living below the national poverty line increased from 35 percent in 2005 to 54 percent in 2011 because of the ongoing conflict

6.5.6 Conflict to child stunting

A direct comparison of the impact of conflict on child stunting, and more generally child undernourishment, is not possible given differences between studies and the still relatively limited evidence base. However, there have been studies quantifying effects of conflict on child stunting—and child undernourishment more generally.

Conflict has a negative effect on child stunting, and other indicators of child malnutrition, with many effects manifesting during but also after conflict (Table 8). A study of child stunting in Burundi found that children exposed to war have on average 0.515 standard deviations lower height-for-age z-scores than non-exposed children (Bundervoet, Verwimp, and Akresh 2009). The effects of conflict on height aren't necessarily constrained to young children. A study in Nigeria found that girls zero to three years old exposed to war were on average 0.75 cm shorter in stature in adulthood compared to women not exposed to war, whereas women 13 to16 years old exposed to war were on average 4.5 cm shorter. Other studies have looked at the effects of conflict on child malnutrition more generally. A case study of Kurdish refugees in Iraq concluded that children 12 to 24 months old experienced significant weight loss and acute malnutrition at a rate three times higher than the normal range prior or after the crisis (Ayala and Meier 2017; Bahwere 2014; Yip and Sharp 1993). However, none of these studies allow for a direct comparison between COVID-19 effects on child stunting relative to the effects of conflict.

Very few studies have attempted to forecast child malnourishment in the future, let alone quantify the effect of conflict thereon. Much of the work that has been done uses the IFs model. A cross-country study quantifies the impact of changing conflict by 0.5 standard deviations on severe wasting. It found that increasing conflict creates a range of 19.5–29.3 million severe wasting cases in 2030 (Moyer et al. 2020). Another report using the IFs model compares malnourished children in North-East Nigeria in 2030 under a "no-conflict" and "conflict" scenario. In 2030 in a "no-conflict" future, 22.2 percent of children (760,000) are projected to be malnourished in North-East Nigeria. This increases to 37.4 percent of children (1.37 million) if conflict continues until 2030 (Hanna et al. 2020). Another IFs study on the impact of conflict projects that conflict could increase childhood malnutrition in Yemen from 25.6 percent (no-conflict) to 95.5 percent (with conflict) in 2030 (Moyer et al., 2019b). These studies provide initial insights into the magnitude that prolonged multi-year conflict can have on indicators of child nutrition. Clearly these effects surpass the impact of COVID-19 on child stunting in 2020, as well as out to 2040. However, the uncertainty in projecting conflict across nations, and the associated severity and duration, result in a limited understanding of the range of conflict on child stunting.

Table 8: Overview of literature estimating an effect of conflict on child stunting and other indicators of child malnutrition.

Reference	Timing	Indicator	Country	Findings
Bundervoet et al. (2009)	Post-conflict	Access—Malnutrition (HAZ)	Burundi	Children exposed to war have on average 0.515 standards deviations lower height-for-age Z-score than non-exposed children.
Yip and Sharp (1993)	During and Post-conflict	Access and utilization—Malnutrition	Syria	Refugee children 12–24 months old experienced significant weight loss, and acute malnutrition was 3x higher than the normal range.
Akresh et al. (2012)	Post-conflict	Utilization—height	Nigeria (Biafra)	Women exposed to the Nigerian Civil War between 0 and 3 years old are 0.75 cm shorter than non-exposed women of the same age. Women exposed during adolescence (13 to 16 years old) are 4.5 cm shorter than non-exposed women of the same age.

6.6 Summary of findings on conflict, climate, and COVID-19

Climate change and conflict are expected to impact the supply, access, and utilization dimensions of food security, particularly among the worlds' most vulnerable populations. Agriculture-dependent communities will likely face the brunt of climate-induced food availability and access constraints. An increase in food- and water-borne disease under climate change reduces a populations' ability to safely use their food, contributing to a vicious cycle of disease and reduced nutritional uptake.

The conflict-food security nexus follows a similar pattern. Conflict destroys production and distribution infrastructure, devastates economies and incomes, and limits access to clean water and sanitation. These negative impacts are concentrated among the most vulnerable populations. In the case of conflict, women and children tend to be more vulnerable than men to poverty, undernutrition, and food insecurity in general.

Both climate change and conflict projections are marked by significant uncertainty. The CO_2-fertilization effect yields substantial ranges in the extent and direction of the impact of climate change. The future of conflict is also highly uncertain, with some projections suggesting conflict could increase, while others anticipate the continuation of post-Cold War trends toward greater peace and stability. Though patterns can be difficult to anticipate, the future of climate change and conflict remain significant and uncertain drivers of future food insecurity.

Analytical insight

Climate change, conflict and COVID-19 affect food security indicators through unique pathways. For example, climate change projections primarily focus on agricultural supply effects, and to a lesser extent on food access and utilization. COVID-19 effects primarily manifest through demand-side effects on food access.

In comparing the effect of these three risk factors, we note significant differences in: a) the pathways through which each risk factor impacts food security; b) our understanding of the risk factor and its effects; and c) the geographic distribution of the drivers.

While climate change and conflict impact food security through all three dimensions of food security, the primary pathway from COVID-19 to food insecurity is reduced income and food demand. COVID-19 has little to no effect on food availability and its impacts on utilization occur only over time. Like COVID-19, conflict and climate are expected to reduce food demands through income reductions. In the case of conflict, supply and utilization are also frequently affected. And in terms of climate change, food demand effects tend to be overshadowed by the influence of climate on food availability systems.

Another key distinction is the degree to which we understand climate change, conflict, and COVID-19. The full effects of climate change are primarily a future challenge, although these effects are increasingly apparent. Uncertainties associated with the CO_2-fertilization effect and greenhouse gas emissions limit our ability to understand climate changes' potential impact. COVID-19 and conflict are also highly uncertain disruptions. The effects of COVID-19 and conflict shift development in unique ways depending on context and population, and it can be difficult to anticipate where and when pandemic and conflict events may occur. But COVID-19 and conflict are problems we have experience with. While the development consequences and variants of COVID-19 are still evolving, we have seen firsthand the outbreak of the pandemic and many of the devastating consequences. Similarly, conflict has influenced food security for generations, providing substantial historical evidence on how conflict influences food systems.

The final point of distinction is the geographic distribution of the three negative trends. COVID-19 is global in scope, though it will impact regions differently. Comparably, climate change is a global phenomenon with localized discrepancies. Conflict, in contrast, tends to be localized, driven largely by the character of conflict and local structure of development.

Lastly, it is important to note the main point of continuity for all three disruptions; Climate change, conflict, and COVID-19 disproportionately impact the poorest and most vulnerable populations. For this reason, socioeconomic development is critical to mitigating the negative impacts of climate change, conflict, and COVID-19 on food insecurity. To situate conflict, COVID-19, and climate change more broadly as risk factors driving future patterns of global food security, it is crucial to recognize that these are not the only drivers of human development outcomes. Much research also suggests that the future character and level of human development will be driven by other factors outside the scope of this study and that the future of food security is much more uncertain because of future patterns of economic growth, policy priorities, demographic trends, and the diffusion of technology (Dickerson, Cannon, and O'Neill 2020; Hasegawa et al. 2018; Schmidhuber and Tubiello 2007).

7. Appendices

Appendix A - List of Participants at Expert Meetings

The following people participated in the expert meetings on scenario design for the COVID-19 scenarios about economic growth, inequality, government debt, and education:

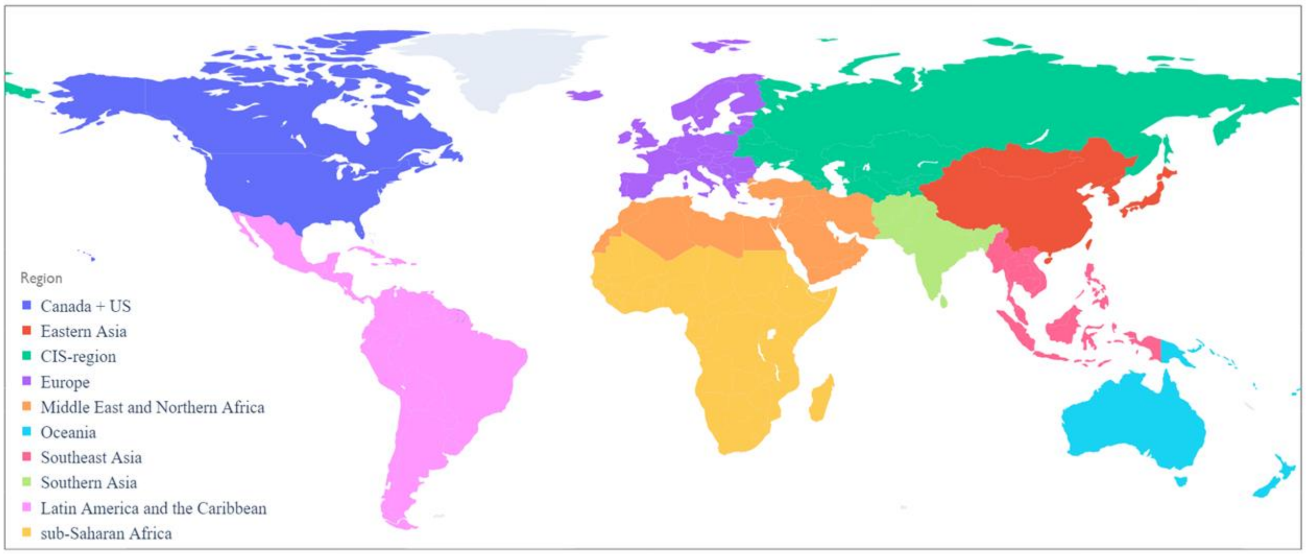
- Samantha Alvis, United States Agency for International Development
- Daniel Gerszon Mahler, World Bank
- Susannah Hares, Center for Global Development
- Barry Hughes, Pardee Center for International Futures
- Mohammad Irfan, Pardee Center for International Futures
- Christoph Lakner, World Bank
- Cedric Okou, World Bank
- Sherman Robinson, International Food Policy Research Institute
- Prachi Srivastava, University of Western Ontario
- James Thurlow, International Food Policy Research Institute
- Vasilis Tsiropoulos, World Bank
- Nina Weisenhorn, United States Agency for International Development

The first meeting introduced the project and the structure of the IFs model. Meetings 2 to 5 were expert elicitations focused on COVID-19 and economic recovery, COVID-19 and inequality, COVID-19 and education, and COVID-19 and government debt. We used the meetings to inform the general scenario framework and the specific scenario assumptions and to discuss the main drivers and uncertainties associated with COVID-19 and individual systems. A sixth meeting was organized to present the result scenarios and discuss results and policy implications.

Appendix B - World Regions

Figure 30 depicts the world regions used in the analysis. We use the same groupings as Janssens et al. (2020) to allow for easier comparison between our COVID-19 results and climate change studies (see Section 6). We distinguish a total of 10 world regions: Canada and the U.S., Latin America and the Caribbean, Europe, Commonwealth of Independent States, Middle East and North Africa, sub-Saharan Africa, Southern Asia (India+), Eastern Asia (China+), Southeast Asia, and Oceania.

Figure 30: World regions used in the analysis. These regions are Canada and the U.S., Latin America and the Caribbean, sub-Saharan Africa, Europe, Commonwealth of Independent States, Middle East and North Africa, Southern Asia (India+), Eastern Asia (China+) Southeast Asia, and Oceania.

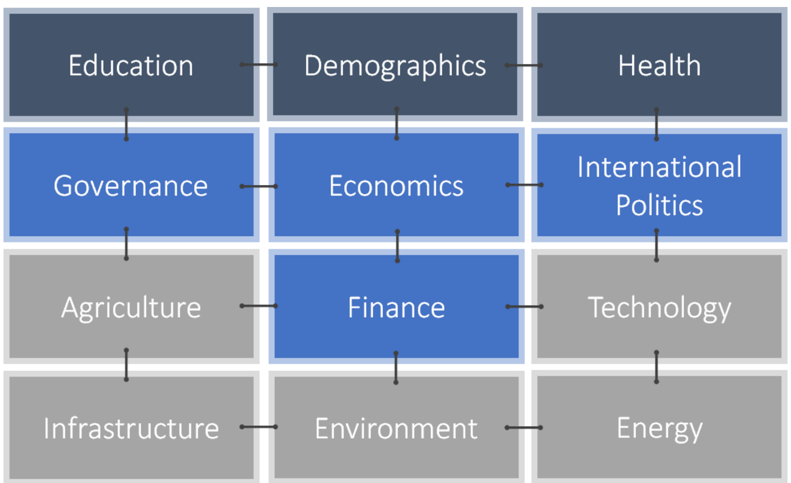


Source: Authors' elaboration.

Appendix C - The International Futures Model

IFs is a tool for thinking about long-term, country-specific, regional, national, and global futures. IFs integrates forecasts for different sub-models, including population, economy, agriculture, education, energy, sociopolitical, international political, environment, technology, infrastructure, and health (Figure 31). These sub-models are dynamically connected, so IFs simulates how changes in one system lead to changes against all other systems. As a result, IFs endogenizes more relationships from a wider range of key global systems than any other model in the world.[22]

Figure 31: Stylistic representation of the sub-models of the International Futures model and the interactions between them.



Note: This representation does not depict all the interactions between the submodules. Dark blue refers to the human development system, light blue refers to the governance and socioeconomic system, and grey refers to the components of the (bio)physical system represented in the IFs model.
Source: Authors' elaboration.

IFs leverages historical data (over 4,500 historical series), identifies and measures trends, and models dynamic relationships to forecast hundreds of variables for 186 countries for every year from 2017 to 2100. IFs is used to help understand dynamics within and among global systems, thereby allowing users to think systematically about potential futures as well as development goals and targets. There are three main avenues for analysis in IFs: historical data analysis (cross-sectional and longitudinal); *Current Path* analysis (where systems seem to be developing); and alternative scenario development (exploring if-then statements about the future). No software can predict the future. IFs forecasts are informed extensions of current trends and dynamics built on our current knowledge of development patterns.

Broadly speaking, the IFs model fits into the history of system dynamics and integrated assessment models. System dynamic models aim to represent the world as an interconnected system, in which positive and negative feedback loops between system components jointly drive development in economic, environment and human systems. Many of the concepts of system dynamics modeling have later been adopted by the integrated assessment modeling community, which primarily focuses on studying the interactions between the climate and the economic system. A famous example is the Dynamic-Integrated Climate-Economy model or DICE from Nobel laureate William Nordhaus

[22] IFs is free to download or use online from: http://pardee.du.edu

(Nordhaus 2018). These integrated assessment models are primarily used to study the interactions between socioeconomic and climate change and the effects of mitigation and adaptation policies (van Vuuren et al. 2011; O'Neill et al. 2014). The IFs model has characteristics of both modeling philosophies by connecting a climate and economic model, as well as more broadly assessing development across a wider set of integrated connected systems.

The Economic Model

A core component of the IFs model is the economic model with connections with all other sub-models in IFs. For studies on food security, the economic model forecasts economic growth and, consequently, changes in average household income central to understanding extreme poverty, undernourishment, and child stunting. The model also captures changes in agricultural economy, agricultural trade, and production. The IFs economic model is documented in academic literature and policy reports (Hughes and Narayan 2021), and all relevant documentation is publicly available.[23] Here we provide an overview of some core concepts of the economics model, largely building on existing documentation.

The treatment of economics in IFs draws on both the classical tradition's focus on economic growth (with great attention in IFs to the newer work on endogenous growth theory) and the neoclassical perspective's general equilibrium approach.

The economic module is a core component of the IFs system for multiple reasons: in particular for its close interactions with all other modules. On the input side, variables from almost all other modules affect production levels. On the output side, the magnitude of GDP and the level of GDP per capita are critical for essentially all other modules. Most closely linked to the economic module are the energy and agriculture modules, both of which use a partial equilibrium structure that echoes the one in the economic module, and both of which provide physical values that fully determine the currency value-based representations of their respective sectors in the economic model.

Basic economic variables include GDP at market exchange rates, GDP at purchasing power parity, GDP per capita at market exchange rates, and GDP per capita at purchasing power parity. The model represents all of these in constant 2011 dollars and includes a representation of the portion of the economy that is informal.

The supply side of the economic module is based on the Cobb-Douglas production function:

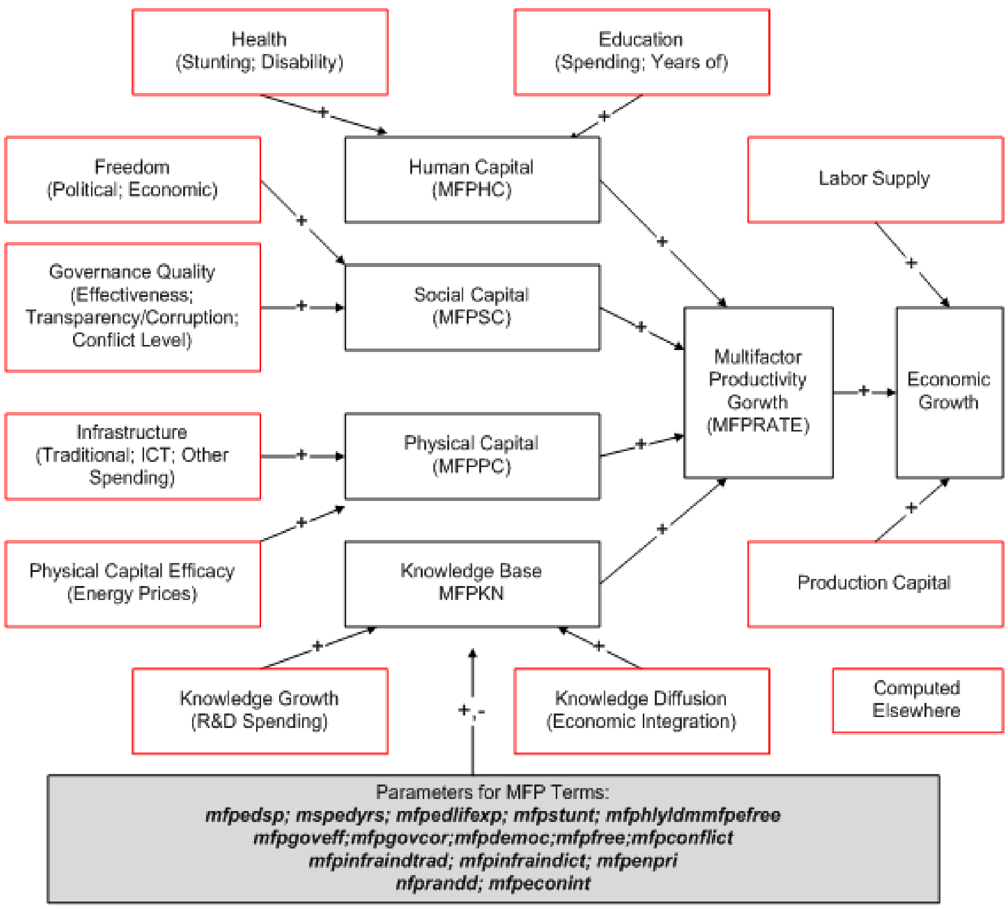
$$VADD_{r,s} = MFP_{r,s} * \ CAPUT_{r,s} * \ KS_{r,s}^{\alpha} * \ LABS_{r,s}^{(1-\alpha)},$$

The function uses labor, capital, and multifactor productivity (MFP) as the primary drivers of economic growth. In the above equation, capital stock (KS) is a function of investment and depreciation rates, labor supply (LABS) is determined from population and endogenously derived labor force participation rates, and there's an exogenous capacity utilization (CAPUT). Value add and each factor of production are specific to the country (r) and sector(s). In the COVID scenarios, the economic shock is distributed across the capacity utilization and productivity terms, with 20 percent passing through to MFP in the *Current Path* scenario, and *Unequal Paths* scenario.

[23] For the full documentation of the IFs economic model the interested reader is referred to our open-source wiki page: https://pardee.du.edu/wiki/Economics

While the treatment of capital and labor in the IFs system will be familiar to users with an understanding of neoclassical economics, the treatment of productivity within IFs deserves greater explanation. Unlike most neoclassical models, which primarily focus on technology as the determining factor of productivity in their equations, the IFs system uses MFP, which is a broader definition of productivity. The MFP term in IFs has four basic components: human (MFPHC), social (MFPSC), physical (MFPPC), and knowledge capital productivity (MFPKN) (Figure 32). Each of these components can take on a positive or negative value, depending on whether the calculated value of the component is providing a positive or negative impact to economic growth rates relative to what would be expected based on the country's level of development.

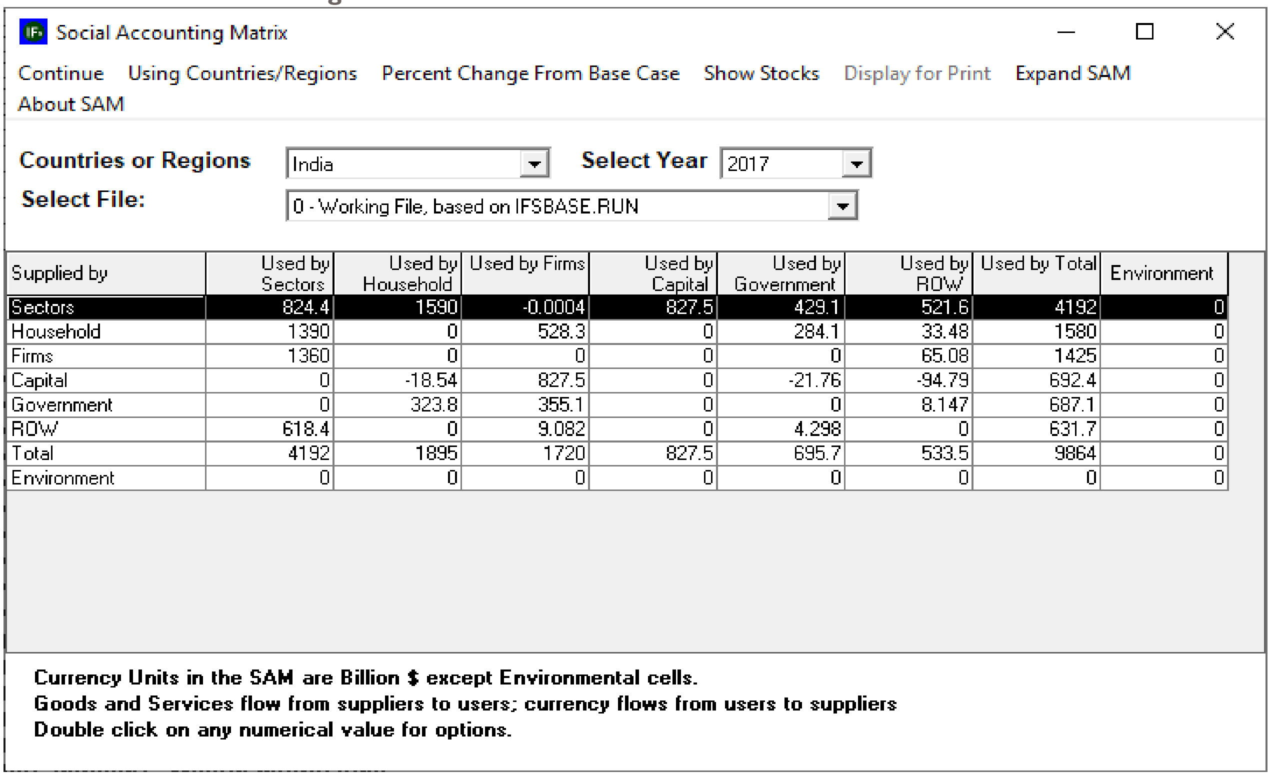
Figure 32: A stylistic representation of the IFs economic growth model.



Note: Economic growth (far right) is driven by labor supply, production capital, and MFP. MFP is driven by the four components of human capital, social capital, physical capital, and knowledge base, which themselves are linked to other sub-models in IFs about education, health, governance, and infrastructure.
Source: International Futures (IFs) model. Frederick S. Pardee Center for International Futures, Josef Korbel School of International Studies, University of Denver, Denver, CO.

Drivers of MFP vary by component. MFPHC is driven by years of education, education expenditures, life expectancy, and health expenditures. MFPSC is driven by Freedom House's measure of political freedom (a variable describing democracy), governance effectiveness, corruption perceptions, and economic freedom. MFPPC is driven by two separate indices of infrastructure: traditional (roads, electricity, and water and sanitation) and information and communication technology. Finally, MFPKN is driven by research and development expenditures and economic integration. This final component of MFP represents a measure of connectedness to the global economy. Thus, changes in other sub-models of IFs will result in changes to the relevant component of multifactor productivity and therefore to economic growth.[24]

Figure 33: Example of a condensed Social Accounting Matrix (SAM) for IFs in India in 2017 with a differentiation the flow of goods and services across sectors and actors.



Supplied by	Used by Sectors	Used by Household	Used by Firms	Used by Capital	Used by Government	Used by ROW	Used by Total	Environment
Sectors	824.4	1590	-0.0004	827.5	429.1	521.6	4192	0
Household	1390	0	528.3	0	284.1	33.48	1580	0
Firms	1360	0	0	0	0	65.08	1425	0
Capital	0	-18.54	827.5	0	-21.76	-94.79	692.4	0
Government	0	323.8	355.1	0	0	8.147	687.1	0
ROW	618.4	0	9.082	0	4.298	0	631.7	0
Total	4192	1895	1720	827.5	695.7	533.5	9864	0
Environment	0	0	0	0	0	0	0	0

Source: International Futures (IFs) modeling system, Version 7.68. Frederick S. Pardee Center for International Futures, Josef Korbel School of International Studies, University of Denver, Denver, CO.

The production function is embedded in a six-sector model of the economy featuring agriculture, raw materials, energy, manufactures, services, and information and communication technology that balances domestic demand and trade in a general equilibrium-seeking structure. Production and consumption of goods and services are in turn incorporated into a larger SAM, which represents the behavior and financial interaction of households, firms, and government (Figure 33). A SAM traditionally represents *flows* among different economic sectors and agent categories (e.g., households, firms, and government). For instance, it represents private consumption and net national savings, as well as household income and savings; firm income, investment by sector, and savings; government revenues, total expenditures with transfers, transfers to households, directed consumption in total, and by sector, and balance. IFs builds a full and balanced SAM of these and many other inter-agent flows. It also creates a second matrix that represents financial *stocks* (assets and liabilities) of different agent categories for all countries in the system, including, for instance, government debt. The representation of stocks in this fashion provides the foundation on which the system adjusts flows of finance among different agents and

[24] For more information on the use and specification of multifactor productivity in IFs, see Hughes and Narayan (2021).

among countries over time, maintaining consistency with the liability-asset approach used in standard accounting systems.

The behavior of agents within this system is not fixed, as in many computable general equilibrium models (which use SAMs commonly). Instead, agent behavior is partially endogenized using algorithms that allow the behavior of agents to shift depending on the levels of stocks of relevant variables within the SAM. So, for example, different levels of government debt trigger different patterns of government expenditures and revenues in IFs, with forward effects on spending on education and water and sanitation infrastructure that in turn affect indicators of food security over time.

Multifactor productivity and the SAM are two areas in the model deeply imbedded within many different systems in IFs. They both directly drive and are driven by changes in human, social, and physical variables and, as such, are key to evaluating trade-offs and synergies across and between alternative interventions.

The Agricultural Model

The IFs agricultural model is a partial equilibrium model that connects the agricultural economy and the agricultural production system to forecast long-term trends in agricultural demand, agricultural production, land under cultivation, production intensity, and international food trade. The IFs agricultural model forecasts production in crops, meat, and fish and distinguishes five land use categories (cropland, grazing land, forests, urban, and other land). The model focuses on forecasting foodstuffs, but also accounts for feed and industrial demand of food crops. A core concept of the agricultural model is that agricultural production globally aims to meet agricultural demand, and global food underproduction would not occur in a baseline development scenario. At the national level, domestic agricultural production supplemented by international food trade and changes to food stock aim to meet agricultural demand. Data on agricultural land, production, and trade primarily come from the FAO food balance sheets. A full description of the IFs agricultural model can be found at Agriculture - Wiki (du.edu). Here we describe the key features of the IFs agricultural model and the updates undertaken for this project, with a focus on the agricultural crop system, given its disproportionate share in caloric consumption and thus food security.

Agricultural demand, expressed as total per capita caloric demand, is a function of changes in household income, consumption patterns, and changes in overall population. Thus, agricultural demand is strongly linked to the population and economic models of IFs. Long-term forecasts of total per capita calorie demand are driven by changes in GDP per capita (a proxy for income). GDP per capita alters the total calorie demand per capita. Moreover, changes in GDP per capita also result in a dietary shift with more affluent populations shifting to a more protein-based diet of meat and fish. The overall food demand is limited by constraints on maximum calories per capita demanded and a maximum caloric demand for meat and fish. More importantly, the total agricultural demand is checked against the ability of households, through household consumption, to afford the total demand. In general, households have the ability to shift consumption. Consumption on agricultural products is protected, meaning that in the case of limited resources, consumption on food is being prioritized and protected as much as possible. The COVID-19 economic crisis affects food demand by lowering GDP per capita. The direct effect of a reduction in GDP per capita on total caloric demand is partly ameliorated through shifts in household consumption, the use of savings to minimize losses in household consumption, and dietary shifts toward crop consumption.

To meet rising agricultural demands over time, countries either produce more food or change agricultural trade patterns. In its most simple form, agricultural production is a function of land under cultivation (in ha) and yield in million metric tons per ha such that:

$$AG\ Production\ pre\ Loss_{country,year} = Cropland_{country,year} * Yield_{country,year}$$

The IFs agricultural model uses a yield saturating forecast with diminishing returns to investment and a Cobb-Douglas production function. This mimics the previous formulation of value add in the economic model. The core inputs are labor supply (LABS), capital stock in agriculture (KAG), a technological growth function (AgTec), a saturation value (SATK), and a scalar (cD) such that:

$$BaseYield_{country,year} = \left(1 + AGTEC_{country,year}\right) * cD_{country} * KAG_{country,year}^{alpha} * LABS_{country,year}^{1-alpha}$$

The growth in technology, labor, and capital all are informed by the economic module. The alpha is the Cobb-Douglas coefficient reflecting the relative elasticities of increasing an input of capital or labor to yield and is calculated on a yearly basis using information from the Global Trade Analysis Project database (Global Trade Analysis Project 2018), in combination with changes in GDP per capita.

Yields cannot increase indefinitely but are bounded by biophysical constraints and management techniques to optimize the use of nutrients and water. Both differ between countries. For this project, we updated the saturation of yields, using data on yield gaps (Mueller et al. 2012; van Ittersum et al. 2016; van Zeist et al. 2020). Yield gaps describe the difference between the actual yield and the maximum attainable yield with optimal techniques, within a biophysical climate-unit. We used data on cereal yield gaps, at the national level from Mueller et al. (2012), to calculate maximum attainable yields:

$$MaximumYield_{country} = Yield2017_{country}/YieldGap_{country}$$

The saturation coefficient is then a function of the difference between the actual yield each year and the maximum yield for that country:

$$SATK_{country,year} = 1 - \frac{Yield_{country,year}}{MaximumYield_{country}}$$

The growth in yield from year-to-year is then constrained by the saturation coefficient, such that the closer a country is to its maximum yield, the more difficult it becomes to increase yields further:

$$BaseYield_{country,year} = Yield2017_{country} + ((BaseYield_{country,year} - Yield2017_{country}) * SATK_{country,year})$$

Following other global cropland models (Neumann et al. 2010; Van Asselen and Verburg 2013), we assume that the cereal yield gap is a good indicator of yield gaps among all crops. Cereals are the most important crops around the world and occupy the largest share of production. As such the production intensity of cereal crops is likely to be a good approximation of the production intensity of other crops.

Yield gaps are especially high in sub-Saharan Africa, and more generally in low-income countries. Incorporating yields gaps into the biophysical constraints allows for relatively more potential growth in countries with high agricultural potentials, and limits yield increases to country-specific biophysical constraints. It also allows for future analysis on the potential of the agricultural sector, i.e. what would overcoming yield gaps in sub-Saharan Africa mean for food security and more generally human development (see for an example van Ittersum et al. 2016).

The other component of production relates to land under cultivation. The IFs agricultural model has a non-spatial land use routine distinguishing five land use types at the country level. Expansion and contraction of cropland are governed by changes in agricultural investment. Investments in agriculture are an output from the economic module and must be allocated across investments in yield and investments in land. The share of investment going to land is based on an initial share of investment going to land and, for the forecast years, depends on the relative returns of investing in one unit of yield increase versus a unit of land increase. Returns on investments from yield diminish with higher yield intensities and yield saturation, and similarly returns on investment from land reduce if more land is under cultivation.

As there are biophysical maximums to yield increases so, too, are there biophysical and economic maximums to cropland expansion. Global estimates for potential arable land vary widely between different approaches and depend on biophysical constraints but also on more definitional issues of what potential is. For example, maximum cropland expansion can be based solely on land suitability from soil and climatic conditions, or it can further lower available land for expansion by taking into consideration the protected area networks and other human agency considerations. To account for this variation, a study by Eitelberg et al. (2015) provides a three-range estimate (low, medium, high) of arable land potential, varying between 1,867 MH to 5,333 MH globally. Here we updated the agricultural model to integrate all three potential arable land ranges. We aggregated the spatial data from Eitelberg et al. (2015) to country-level estimates. We then calculated the difference between current arable land in use and the arable land potential. Similar to other global crop models, returns on investment diminish the larger the share of the potential arable land in use (Doelman et al. 2018). The inclusion of the maximum potential arable land, and the three levels, allow us to explore the potential of maximum country-level land expansion under different policy constraints, and to assess the effect of land expansion on food security, and more general on human development and climate change. All scenarios presented in this report use the high range of potential arable land.

The IFs model has a simplified climate change routine with endogenous feedbacks between economic growth and emissions and forward effects from global climate change to agricultural yields. There are two general approaches for linking economic growth and climate change into integrated modeling exercises. One option is to separate the two by exogenous prescriptions of emission pathways, Representative Concentrations Pathways (van Vuuren et al. 2011), with exogenous scenario prescriptions on socioeconomic developments, Shared Socioeconomic Pathways (O'Neill et al. 2014). Another approach links socioeconomic development and climate change endogenous with simplified relationships and feedback loops between economic growth and climate change (Nordhaus 2018). The emission scenario used in the IFs model fall between 4.5 and 6.0 RCP, with a projected global CO_2-concentration of 522.1 parts per million by 2050. Like RCP 4.5, it projects a slowing down of the CO_2 concentration after mid-century. All scenarios in this report have roughly the same climate pathway, although changes in the economic model from COVID-19 allow for slight deviations in the emission pathway.

Climate change has a dual effect on crop production. Following the ISIMIP protocol, we account for CO_2-fertilization, which positively affects yield with higher CO_2-concentration. At the same time, changes in global mean temperature and precipitation patterns negatively affect plant growth for most regions, due to drier and warmer climatic conditions. This results in negative feedback to plant growth, especially in world regions in temperate and tropical latitudes. Overall, by 2050 the climate-induced change in crop production for different world regions varies, with a slight positive to no net effect in northern latitudes and reductions in yield varying between -4.0 percent in Southeast Asia to -5.8 percent in sub-Saharan Africa by mid-century. While climate change can also affect arable land potential, there have been very few studies that estimate the extent of this for all countries globally. Therefore, we assume no effect of climate change on arable land potential.

Many countries are not able to meet agricultural demand based purely on domestic production, and for the next decades growth in agricultural demand in sub-Saharan Africa is projected to outpace growth in production. Agricultural trade can be used to supplement insufficient domestic production and make food availability meet demand, albeit with increasing levels of food import dependence. The future challenge will be to continue to meet agricultural demand at the national level, with socioeconomic trends resulting in a growing and more affluent population in many food insecure countries on the one hand and biophysical constraints imposed to expanding global crop production from land availability, yield plateaus, and rising impacts of climate change on the other hand. The future of food security will thus be shaped by interactions between the socioeconomic system and the agricultural and biophysical systems, and IFs—with their associated positive and negative feedback loops—provides a unique tool to study long-term projections integrating all these systems together.

Forecasting Poverty in IFs

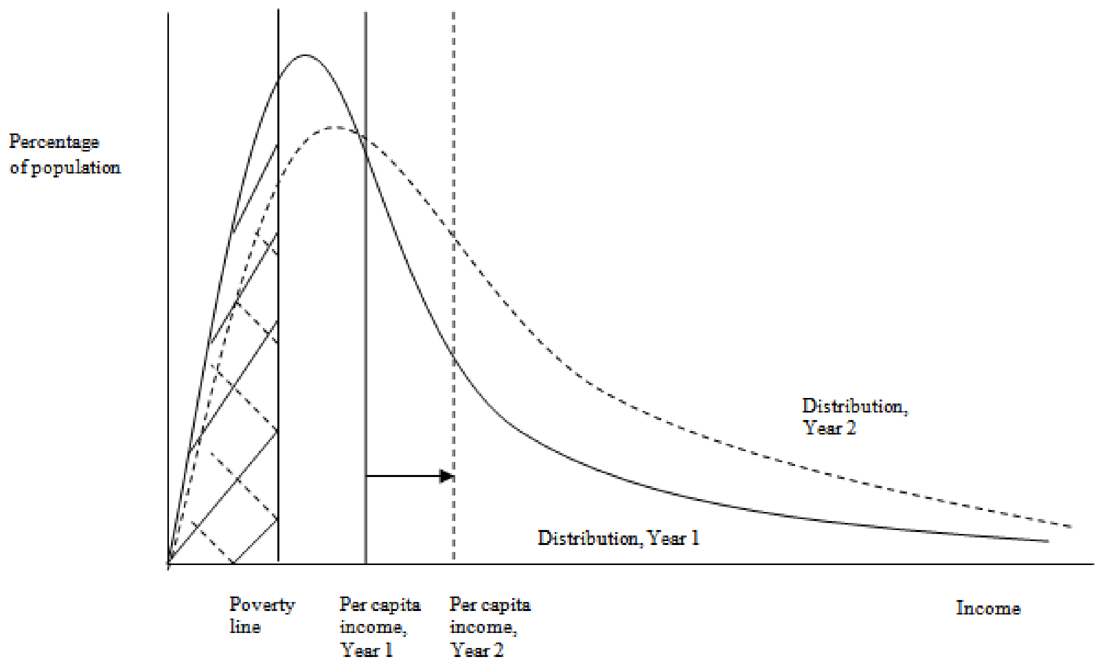
The IFs model forecasts extreme poverty for 186 countries based on dynamically connected representations of economic growth, income distribution, and demographic change. Poverty projections in IFs and the underlying methodological description have been published in academic and non-academic literature; here we provide a more concise overview (Milante, Hughes, and Burt 2016; Hughes 2019; Moyer and Bohl 2018; Moyer and Hedden 2020).

Economic growth drives changes in household income. The forecasts of economic growth have been described in the previous section, on the economic model in IFs. The other component relates to the need to understand and forecast the distribution of income among households in society. The IFs approach uses a log-normal distribution of household income among all countries. The log-normal distribution is the most widely used distribution of household income, offers important advantages for long-term forecasts and has been empirically tested (Bourguignon 2004; Shorrocks and Wan 2008). Figure 34 provides an example of a log-normal distribution, or bell-curve, for income used in the IFs model.

One advantage of using a log-normal density to capture the distribution of income in a society is that it can be fully specified with only two parameters: average income and the standard deviation of it. Mean household consumption, logged, is used as the distribution variable and the Gini-coefficient of income inequality for the standard deviation of the logged distribution variable. Forecasts are initialized using data from PovCalNet for different poverty thresholds (World Bank 2021d). Using the log-normal distribution along with with the mean household consumption provides us with an approximation of the distribution of income within a country. The last component is then a minimum threshold value, below which one is considered to live in poverty. The IFs model can produce forecasts using a variety of international thresholds at $1.90 per day, $3.20 per day and $5.50 per day. In this report, we use the $1.90 per day threshold to assess the percentage of the population living in extreme poverty.

Figure 34 provides an example of how changes in per capita income and changes in the Gini-coefficient drive our forecasts of extreme poverty. The changes in per capita income are a consequence of changes in economic growth and population dynamics from the IFs population model. Changes in Gini-coefficient can either be endogenous forecasted or can be exogenous prescribed. Given the uncertainties into how COVID-19 is affecting the Gini-coefficient, we opted for exogenous forecasts in this report. We keep the Gini-coefficient constant at 2019 values and impose scenario-specific changes to the Gini-coefficient at the country level. For individual countries, the Gini-coefficient will be stable from 2020 to 2040 within each scenario, but population growth for countries will slightly change the global average Gini-coefficient between 2020 and 2040.

Figure 34: Example of a log-normal distribution of income and how changes in per capita income, the distribution of income, and the poverty line threshold alter the calculation and forecasts of the percentage of population living in extreme poverty.



Source: Authors' elaboration.

Forecasting Undernourishment in IFs

IFs projections of the PoU follows methods used by FAO and USDA (FAO et al. 2020; Baquedano et al. 2020; Hasegawa et al. 2018), which assume a log-normal distribution of calories described by mean caloric intake (CLPC) and the coefficient of variation (CV) to determine the proportion of a population living under the minimum dietary energy requirement threshold (MDER). It very much resembles the approach used to forecast poverty, with a mean level of calories per capita, a parameter describing the distribution and a minimum threshold value.

While the FAO and USDA both follow a similar approach, they differ in their implementation in three ways. First, FAO establishes a country-specific MDER, whereas USDA uses an average energy requirement set at a calorie target of 2,100 calories per capita per day (Baquedano et al. 2020, pp. 55-56). Second, USDA holds the CV constant throughout the projection period, whereas FAO uses linear interpolation and extrapolation (Baquedano et al. 2020; FAO et al. 2020). Finally, while USDA uses income level as a proxy for minimum food consumption, FAO uses actual per capita dietary energy supply from the food balance sheet.

In IFs, the PoU is initialized by data gathered from the World Bank's World Development Indicators, which actually get their data from FAO (FAO et al. 2020). The data covers 170 countries over 27 years. Data for countries not covered in this series is supplemented with data from the United Nations Statistics Division. For countries not covered in either dataset, IFs estimates initial values using a statistical relationship with calories per capita.

Since the forecast logic of MALNPOP is analogous to the one used in the estimation and forecast of poverty in IFs (see above for more information), the following sections will detail the data, initializations, and projections of its driving variables.

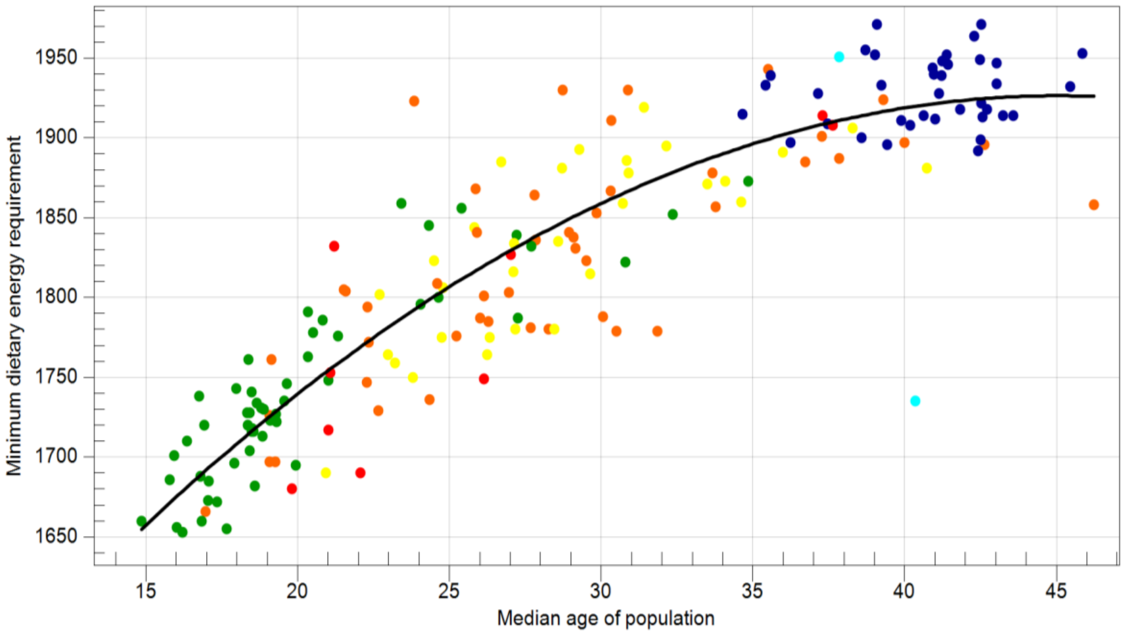
Minimum Dietary Energy Requirement

The MDER for any given country is the cutoff point that FAO uses to determine undernourishment. It is reported in kilocalories/day and is based on the weighted average of minimum energy requirements of different age and sex groups. MDER data for the project came from the FAO's Food Security Indicators and covers 184 countries over 20 years. As Eritrea and Kosovo are not represented in this dataset, we initialize them with data from Ethiopia and Serbia, respectively.

We forecast MDER with a 2nd degree polynomial function, using the median age of the population as the sole independent variable.[25] Differences between data and statistical estimates are preserved through use of a multiplicative shift factor.

[25] For information regarding the initialization and forecast of the median age of population, see https://pardee.du.edu/wiki/Population.

Figure 35: Relationship between the median age of a population and MDER in 2017. The points represent individual countries.



Source: Authors' calculations.

Coefficient of Variation

The CV is a measure of the dispersion of the distribution of the caloric intake within the general population. Higher CV values represent larger dispersion, or higher inequality in caloric intake. Thus, the CV is like the Gini index of income inequality.

Original data for the project was derived from the FAO's Food Security Indicators covering 186 countries over 20 years. Where available, FAO calculates CV using national household survey data. It relies on three approaches, depending on how accessible and reliable country-level survey data is. First, FAO attempts to group average food expenditure by income class. Second, if expenditure data is not available, FAO then turns to survey data distributed by household income, as measured by the Gini-coefficient. Finally, if neither expenditure data nor survey Gini data is available, the third procedure is to estimate CV from data on infant mortality. National household survey data is becoming increasingly available, making the first and second procedures increasingly more likely.

FAO suggests significant uncertainty in the estimation of the PoU's model parameters (including CV), resulting in low precision in its estimates of PoU (FAO et al. 2020). These observations also became clear and posed a significant challenge in the estimation and projections of undernourishment in IFs. In addition, during the construction of the model and writing of this report, FAO ceased to publicly host the dataset. For these reasons, we have decided to initialize the CV with an inferred value-based on data on MDER, prevalence of undernourishment, and the assumed log-normal distribution of calories.

The IFs model allows for an endogenous forecast of the coefficient of variation as well as an exogenous forecast. The endogenous forecast is based on literature linking the coefficient of variation to differences in economic development and accessibility, physical accessibility, and social equality (Iram and Butt 2004; Headey and Alderman 2019; Hasegawa, Fujimori, Takahashi, et al. 2015). However, here we use the same approach as with the Gini-coefficient and exogenous imposed CV values, depending on the scenario.

Forecasting Child Stunting in IFs

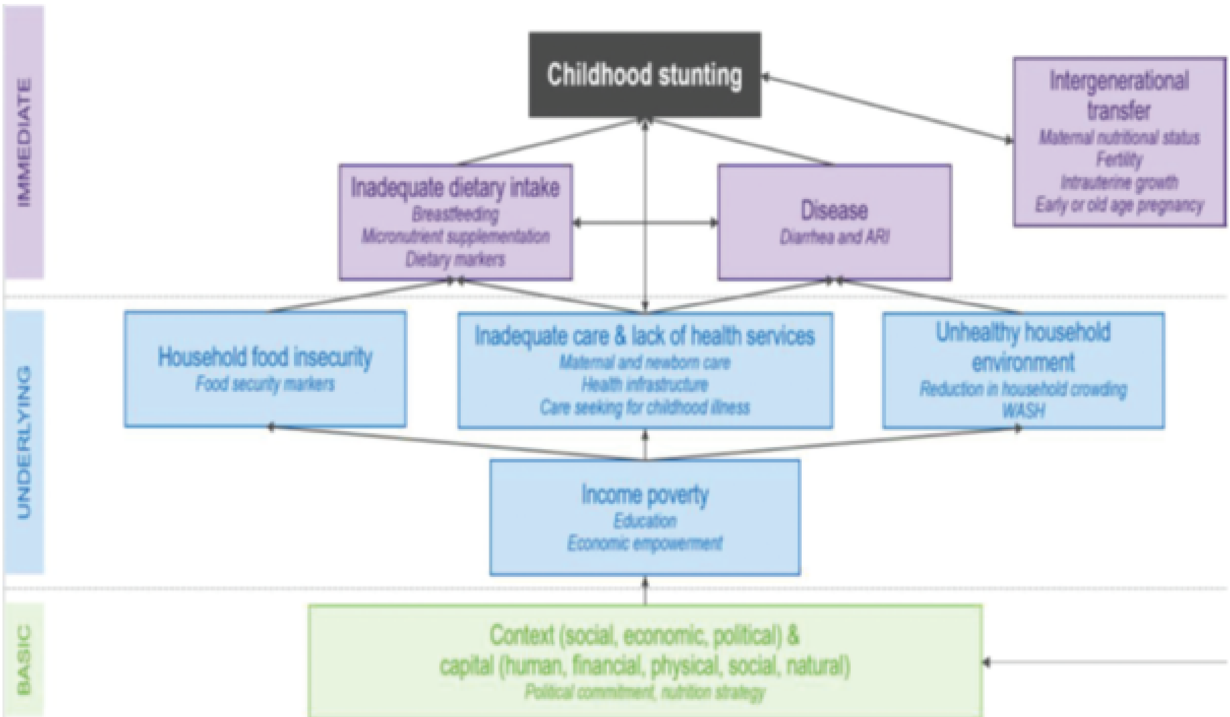
Child stunting refers to children from zero to 59 months of age with a height-for-age ratio greater than two standard deviations (<-2 SD) below the WHO Child Growth Standards median (FAO et al. 2020). In IFs, child stunting is initialized using data from the World Development Indicators compiled by the World Bank from officially recognized sources covering 147 countries over 36 years. For countries without data, child stunting is initialized using initial year values of malnourished children.

A survey of the literature suggested that drivers of child stunting are associated with factors contributing to undernourishment in children, such as disease spread, access to WATSAN, and caloric availability, as well as with the position of mothers in the household, their education levels, access to health and general use of vaccinations, and breastfeeding (Figure 36). Following the review, we undertook a statistical exercise to determine an approximate model. The final model comprised two variables: 1) the percentage of children under the age of five who are underweight relative to their age, which is driven by caloric intake and access to safe WATSAN, and 2) the secondary completion rate of females over the age of 15. Often long-term forecasts need to simplify their approach, and here we ended up with three basic indicators of caloric intake, access to WATSAN, and maternal education. These indicators are drivers in themselves, but many of them are also likely to be associated with immediate drivers of intergenerational transfer, breastfeeding practices, and access to health care facilities. Previous cross-country analysis of long-term trends in child mortality and child stunting has highlighted the strong link to maternal education (Vaivada et al. 2020; Bhutta et al. 2020; Gakidou et al. 2010; Balaj et al. 2021). Thus, maternal education is a driver and considered as a proxy for the factors affecting mothers.

Forecasts of child undernutrition and child stunting are, unlike PoU, largely a result of the underutilization of calories, often from diarrheal disease caused by poor sanitation and contaminated water. In IFs, child undernutrition is forecast as a function of calories per capita (CLPC) and access to safe water (WATSAFE), and improved sanitation (SANITATION) in the governance and infrastructure models. Female secondary completion rate is estimated using the IFs education model and is the result of a system that tracks student flows through primary, lower, and upper secondary levels.[26] Changes in education, infrastructure, and caloric intake jointly drive the forecasts of child stunting at the country level. The IFs model is one of the very few models capable of providing projections on child stunting, with only one other model linking child stunting largely to economic and socioeconomic changes in caloric intake (Lloyd et al. 2018), without accounting for other long-term drivers on WATSAN and maternal education levels.

[26] For more information on the IFs education model, see https://pardee.du.edu/wiki/Education.

Figure 36: Example of conceptual framework from that links childhood stunting to its associated immediate, underlying, and basic drivers.



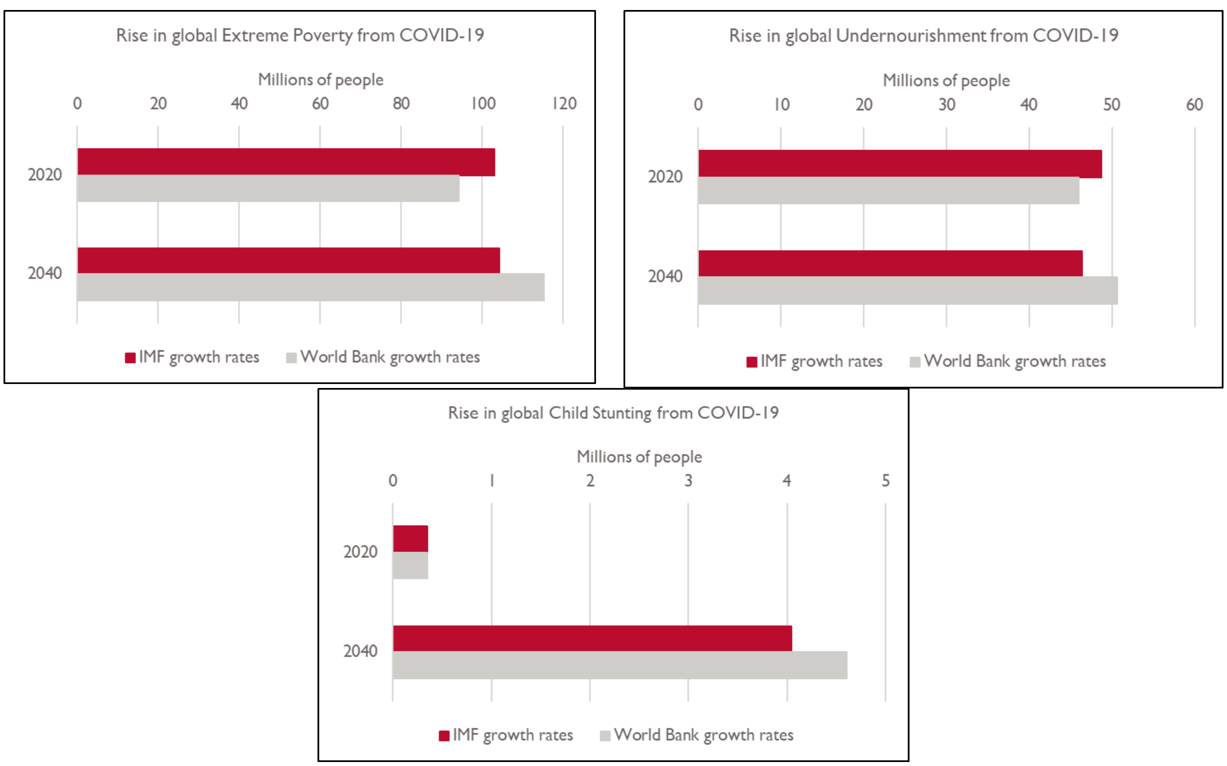
Source: (Akseer, Vaivada, et al. 2020).

Appendix D - Sensitivity analysis on GDP growth rates and distributional effects

Figure 37 depicts the difference in the rise in extreme poverty, undernourishment, and child stunting relative to a *No-COVID* scenario for GDP growth rates from IMF and World Bank. The results are depicted for the *Current Path* scenario. Overall, the differences between the scenario forecasts in 2020 and 2040 are considerably smaller than the difference between the *Current Path* scenario and *Unequal Paths* scenario. In 2020, World Bank GDP growth projections are slightly more optimistic than IMF, resulting in a rise in extreme poverty of 9.8 million fewer people, a rise in undernourishment of 2.7 million fewer people, and equal rises in child stunting. A difference of nearly 10 million people in extreme poverty is important but compared to the overall rise of nearly 100 million people, it is quite small and falls well within the range of forecasts related to rises in poverty and undernourishment.

While the World Bank projects a smaller drop in average global GDP, it also projects a less pronounced recovery in 2021 and 2022. A major difference is the projected recovery in India in 2021, dropping from a projected 12.6 percent by IMF to 8.3 percent by World Bank because of the more recent outbreak of COVID-19 in India and Southern Asia. Consequently, by 2040, projections on poverty, undernourishment, and child stunting result in a higher rise with World Bank GDP growth numbers compared to IMF GDP growth rates, relative to a *No-COVID* scenario. Like 2020, the difference between the GDP growth scenarios is small compared to the overall change in each of these indicators. These results show that the choice to use GDP growth rates from either IMF or World Bank is unlikely to change the overall storyline and trends of how COVID-19 is affecting the future of food security.

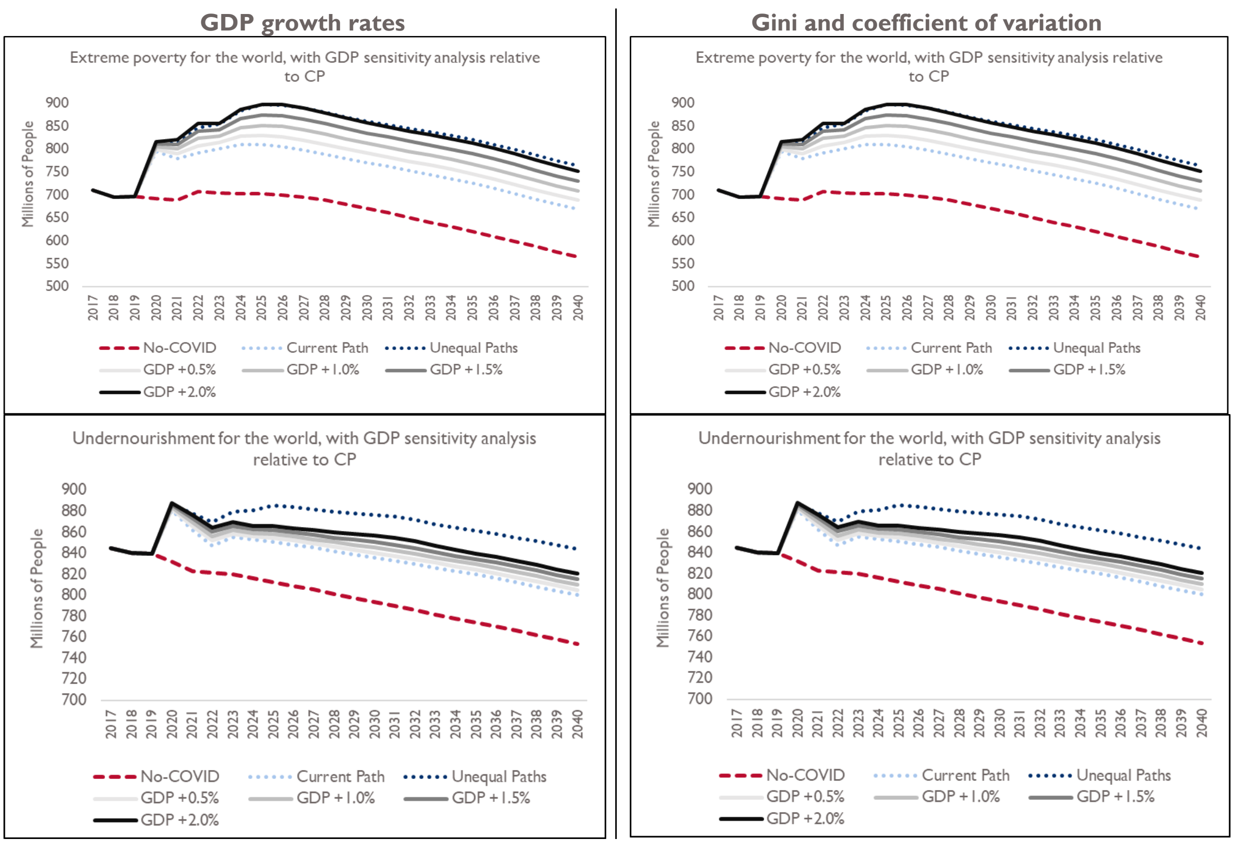
Figure 37: Comparison between a scenario run with IMF GDP growth rates and World Bank GDP growth rates for the effect of COVID-19 on extreme poverty, undernourishment, and child stunting in 2020 and 2040.

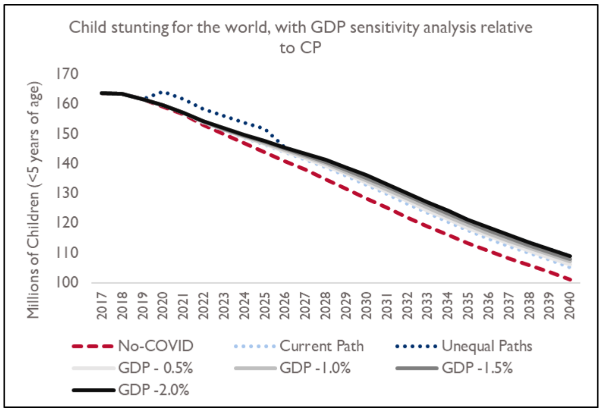


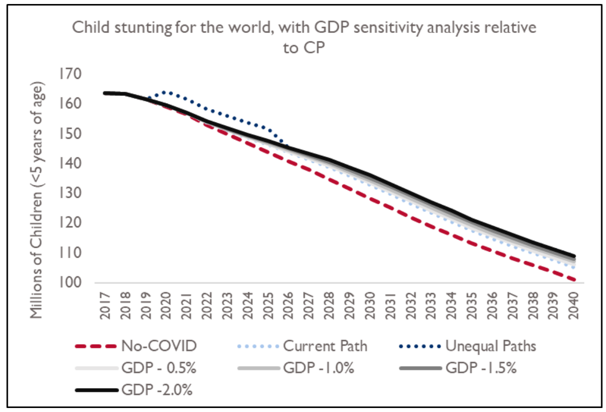
Source: Authors' calculations.

To further assess the importance of GDP growth rate assumptions and distributional effects, we ran a set of additional scenarios with varying assumptions on GDP growth, Gini, and the coefficient of variation (Figure 38). We use the *Current Path* scenario as the starting point, reducing GDP growth rates by -0.5 percent, -1.0 percent, -1.5 percent, and -2.0 percent for all countries from 2020 to 2022. Note that the -1.5 percent change is equivalent to that of the *Unequal Paths* scenario but excludes changes to distribution, education, and government finances in the *Unequal Paths* scenario. For Gini and the coefficient of variation, we change the *Current Path* scenario to assume no change from 2019 values, +0.5 percent, +1.5 percent, +2.0 percent change for all countries from 2020 out to 2040. Note that the +1.0 percent change in Gini and coefficient of variation is the actual setting in the *Current Path* scenario and would have given the same result as depicted by the scenario. Overall, the changes in GDP and distribution fall well within the uncertainty between the *No-COVID* and the two COVID-19 scenarios. Moreover, as shown in the report, extreme poverty is more sensitive to changes in GDP relative to undernourishment, because of opportunities to shift consumption patterns and diet. Undernourishment is more sensitive to changes in distribution, relative to extreme poverty. Child stunting shows limited change for all scenarios, including the sensitivity scenarios.

Figure 38: Uncertainty analysis on GDP growth rates (left panel) and changes in Gini and coefficient of variation (right panel) relative to the *Current Path* scenario. Results are depicted for the global outcomes of extreme poverty, undernourishment, and child stunting from 2017 to 2040.







Source: Authors' calculations.

Bibliography

Abate, G. T., A. de Brauw, and K. Hirvonen. 2020. "Food and Nutrition Security in Addis Ababa, Ethiopia during COVID-19 Pandemic: June 2020 Report." ESSP Working Paper-Ethiopia Strategy Support Program|2020 (145). ESSP Working Paper - Ethiopia Strategy Support Program|2020 (145). Washington D.C.: International Food Policy Research Institute. https://doi.org/10.2499/p15738coll2.133766.

Agrawal, Bina. 2015. "Food Security, Productivity, and Gender Inequality." In *The Oxford Handbook of Food, Politics, and Society*. The Oxford Handbook of Food, Politics, and Society. Oxford, UK: Oxford Handbooks Online. https://www.oxfordhandbooks.com/view/10.1093/oxfordhb/9780195397772.001.0001/oxfordhb-9780195397772-e-002.

Akresh, Richard, Sonia Bhalotra, Marinella Leone, and Una Okonkwo Osili. 2012. "War and Stature: Growing Up during the Nigerian Civil War." *American Economic Review* 102 (3): 273–77. https://doi.org/10.1257/aer.102.3.273.

Akseer, Nadia, Goutham Kandru, Emily C. Keats, and Zulfiqar A. Bhutta. 2020. "COVID-19 Pandemic and Mitigation Strategies: Implications for Maternal and Child Health and Nutrition." *The American Journal of Clinical Nutrition* 112 (2): 251–56. https://doi.org/10.1093/ajcn/nqaa171.

Akseer, Nadia, Tyler Vaivada, Oliver Rothschild, Kevin Ho, and Zulfiqar A Bhutta. 2020. "Understanding Multifactorial Drivers of Child Stunting Reduction in Exemplar Countries: A Mixed-Methods Approach." *The American Journal of Clinical Nutrition* 112 (Supplement_2): 792S-805S. https://doi.org/10.1093/ajcn/nqaa152.

Anderson, Robyn, Philipp E Bayer, and David Edwards. 2020. "Climate Change and the Need for Agricultural Adaptation." *Current Opinion in Plant Biology*, Biotic interactions ● AGRI 2019, 56 (August): 197–202. https://doi.org/10.1016/j.pbi.2019.12.006.

Asselen, Sanneke van, and Peter H. Verburg. 2013. "Land Cover Change or Land-Use Intensification: Simulating Land System Change with a Global-Scale Land Change Model." *Global Change Biology* 19 (12): 3648–67. https://doi.org/10.1111/gcb.12331.

Ayala, Ana, and Benjamin Mason Meier. 2017. "A Human Rights Approach to the Health Implications of Food and Nutrition Insecurity." *Public Health Reviews* 38 (1): 10. https://doi.org/10.1186/s40985-017-0056-5.

Azevedo, Joao Pedro, Amer Hasan, Diana Goldemberg, Syedah Aroob Iqbal, and Koen Geven. 2020. "Simulating the Potential Impacts of COVID-19 School Closures on Schooling and Learning Outcomes: A Set of Global Estimates." World Bank, Washington, DC. https://doi.org/10.1596/1813-9450-9284.

Bahwere, Paluku. 2014. "Severe Acute Malnutrition during Emergencies: Burden Management, and Gaps." *Food and Nutrition Bulletin* 35 (2 Suppl): S47-51. https://doi.org/10.1177/15648265140352S107.

Balaj, Mirza, Hunter Wade York, Kam Sripada, Elodie Besnier, Hanne Dahl Vonen, Aleksandr Aravkin, Joseph Friedman, et al. 2021. "Parental Education and Inequalities in Child Mortality: A Global Systematic Review and Meta-Analysis." *The Lancet* 0 (0). https://doi.org/10.1016/S0140-6736(21)00534-1.

Baldos, Uris Lantz C., and Thomas W. Hertel. 2015. "The Role of International Trade in Managing Food Security Risks from Climate Change." *Food Security* 7 (2): 275–90. https://doi.org/10.1007/s12571-015-0435-z.

Baquedano, Felix, Cheryl Christensen, Kayode Ajewole, and Jayson Beckman. 2020. "International Food Security Assessment, 2020-2030." GFA-31. U.S. Department of Agriculture Economic Research Service.

Baquedano, Felix, Yacob Abrehe Zereyesus, Constanza Valdes, and Kayode Ajewole. 2021. "International Food Security Assessment, 2021–31." US Department of Agriculture, Economic Research Service.

Beckmann, Michael, Katharina Gerstner, Morodoluwa Akin-Fajiye, Silvia Ceaușu, Stephan Kambach, Nicole L. Kinlock, Helen R. P. Phillips, et al. 2019. "Conventional Land-Use Intensification Reduces Species Richness and Increases Production: A Global Meta-Analysis." *Global Change Biology* 25 (6): 1941–56. https://doi.org/10.1111/gcb.14606.

Bello-Schünemann, Julia, and Jonathan D. Moyer. 2018. "Structural Pressures and Political Instability: Trajectories for Sub-Saharan Africa." *SSRN Electronic Journal*, September, 32.

Bernauer, Thomas, Tobias Böhmelt, and Vally Koubi. 2012. "Environmental Changes and Violent Conflict." *Environmental Research Letters* 7 (1): 015601. https://doi.org/10.1088/1748-9326/7/1/015601.

Bhutta, Zulfiqar A., Nadia Akseer, Emily C. Keats, Tyler Vaivada, Shawn Baker, Susan E. Horton, Joanne Katz, et al. 2020. "How Countries Can Reduce Child Stunting at Scale: Lessons from Exemplar Countries." *The American Journal of Clinical Nutrition* 112 (Suppl 2): 894S-904S. https://doi.org/10.1093/ajcn/nqaa153.

Bill & Melinda Gates Foundation, and IHME. 2020. "2020 Goalkeepers Report: COVID-19 A Global Perspective." 2020 Goalkeepers Report. https://www.gatesfoundation.org/goalkeepers/downloads/2020-report/report_a4_en.pdf.

Bircan, Cagatay, Tilman Bruck, and Marc Vothknecht. 2010. "Violent Conflict and Inequality." Discussion Papers 1013. Berlin: Deutsches Institut fur Wirtschaftsforschung. https://papers.ssrn.com/sol3/papers.cfm?abstract_id=1639826.

Blankenship, Jessica L., Jennifer Cashin, Tuan T. Nguyen, and Hedy Ip. 2020. "Childhood Stunting and Wasting in Myanmar: Key Drivers and Implications for Policies and Programmes." *Maternal & Child Nutrition* 16 (S2): e12710. https://doi.org/10.1111/mcn.12710.

Bourguignon, François. 2004. "The Poverty-Growth-Inequality Triangle." Working Paper. New Delhi: Indian Council for Research on International Economic Relations (ICRIER).

Bowlsby, Drew, Erica Chenoweth, Cullen Hendrix, and Jonathan D. Moyer. 2020. "The Future Is a Moving Target: Predicting Political Instability." *British Journal of Political Science* 50 (4): 1405–17. https://doi.org/10.1017/S0007123418000443.

Briend, André, Tanya Khara, and Carmel Dolan. 2015. "Wasting and Stunting—Similarities and Differences: Policy and Programmatic Implications." *Food and Nutrition Bulletin* 36 (1_suppl1): S15–23. https://doi.org/10.1177/15648265150361S103.

Buhaug, Harvard, Nils Petter Gleditsch, and Ole Magnus. 2008. "Climate Change, the Environment, and Armed Conflict." In. Boston, MA. https://www.prio.org/Publications/Publication/?x=3954.

Bundervoet, Tom, Philip Verwimp, and Richard Akresh. 2009. "Health and Civil War in Rural Burundi." *Journal of Human Resources* 44 (2): 536–63. https://doi.org/10.3368/jhr.44.2.536.

Burke, Marshall B., Edward Miguel, Shanker Satyanath, John A. Dykema, and David B. Lobell. 2009. "Warming Increases the Risk of Civil War in Africa." *Proceedings of the National Academy of Sciences* 106 (49): 20670–74. https://doi.org/10.1073/pnas.0907998106.

Burke, Marshall, Solomon M. Hsiang, and Edward Miguel. 2015. "Climate and Conflict." *Http://Dx.Doi.Org.Du.Idm.Oclc.Org/10.1146/Annurev-Economics-080614-115430* 7 (1): 577–617. https://doi.org/10.1146/annurev-economics-080614-115430.

Busby, Joshua. 2017. "Mapping Epicenters of Climate and Security Vulnerabilities." The Center for Climate and Security.

Caner, Mehmet, Thomas Grennes, and Fritzi Koehler-Greib. 2010. "Finding the Tipping Point - When Sovereign Debt Turns Bad." 5391. Policy Research Working Paper Series. Latin America and the Carribean Region: World Bank. http://documents1.worldbank.org/curated/en/509771468337915456/pdf/WPS5391.pdf.

Ceballos, Francisco, Manuel A. Hernandez, and Cynthia Paz. 2021. "Short-term Impacts of COVID-19 on Food Security and Nutrition in Rural Guatemala: Phone-based Farm Household Survey Evidence." *Agricultural Economics* 52 (3): 477–94. https://doi.org/10.1111/agec.12629.

Cederman, Lars-Erik, Nils B. Weidmann, and Kristian Skrede Gleditsch. 2011. "Horizontal Inequalities and Ethnonationalist Civil War: A Global Comparison." *American Political Science Review* 105 (3): 478–95. https://doi.org/10.1017/S0003055411000207.

Chen, Robert S., William H. Bender, Robert W. Kates, E. Messer, and Sara R. Millman. 1990. "The Hunger Report 1990." Providence, Rhode Island: Brown University. https://pdf.usaid.gov/pdf_docs/PDABH899.pdf.

Climate Change 2014: Synthesis Report. Contribution of Working Groups I, II and III to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change. 2015. Geneva, Switzerland: Intergovernmental Panel on Climate Change. https://www.ipcc.ch/site/assets/uploads/2018/02/SYR_AR5_FINAL_full.pdf.

Cousin, Ertharin. 2016. "Hunger as a Weapon of War." *Thomson Reuters Foundation*, December 23, 2016. https://news.trust.org/item/20161223102346-zi51k/.

Dabalen, Andrew L., and Saumik Paul. 2012. "Effect of Conflict on Dietary Energy Supply: Evidence from Cote d'Ivoire." 12/09. *Discussion Papers*. Discussion Papers. University of Nottingham, CREDIT. https://ideas.repec.org/p/not/notcre/12-09.html.

Degomme, Olivier, and Debarati Guha-Sapir. 2010. "Patterns of Mortality Rates in Darfur Conflict." *The Lancet* 375 (9711): 294–300. https://doi.org/10.1016/S0140-6736(09)61967-X.

Dickerson, Sarah, Mallory Cannon, and Brian O'Neill. 2020. "Climate Change Risks to Human Development in Sub-Saharan Africa: A Review of the Literature." *Working Paper*.

Doelman, Jonathan C., Elke Stehfest, Andrzej Tabeau, Hans van Meijl, Luis Lassaletta, David E. H. J. Gernaat, Kathleen Hermans, et al. 2018. "Exploring SSP Land-Use Dynamics Using the IMAGE Model: Regional and Gridded Scenarios of Land-Use Change and Land-Based Climate Change Mitigation." *Global Environmental Change* 48 (January): 119–35. https://doi.org/10.1016/j.gloenvcha.2017.11.014.

Ebi, Kristie L. 2008. "Adaptation Costs for Climate Change-Related Cases of Diarrhoeal Disease, Malnutrition, and Malaria in 2030." *Globalization and Health* 4 (1): 9. https://doi.org/10.1186/1744-8603-4-9.

Eitelberg, David A., Jasper van Vliet, and Peter H. Verburg. 2015. "A Review of Global Potentially Available Cropland Estimates and Their Consequences for Model-Based Assessments." *Global Change Biology* 21 (3): 1236–48. https://doi.org/10.1111/gcb.12733.

Esch, Stefan van der, B. ten Brink, Elke Stehfest, Michel Bakkenes, Annelies Sewell, A. Bouwman, Johan Meijer, et al. 2017. "Exploring Future Changes in Land Use and Land Condition and the Impacts on Food, Water, Climate Change and Biodiversity: Scenarios for the UN Convention to Combat Desertification Global Land Outlook." The Hague, The Netherlands: PBL Netherlands Environmental Assessment Agency. https://www.pbl.nl/en/publications/exploring-future-changes-in-land-use.

FAO. 2008. "An Introduction to the Basic Concepts of Food Security." Fact Sheet. FAO. http://www.fao.org/3/al936e/al936e00.pdf.

———. 2009. "The State of Food Insecurity in the World 2009: Economic Crises Impacts and Lessons Learned." SOFI. Rome, Italy: FAO. http://www.fao.org/3/i0876e/i0876e00.htm.

FAO, IFAD, UNICEF, WFP, and WHO. 2020. *The State of Food Security and Nutrition in the World 2020. Transforming Food Systems for Affordable Healthy Diets.* Rome: FAO. https://doi.org/10.4060/ca9692en.

———. 2021. "The State of Food Security and Nutrition in the World 2021. Transforming Food Systems for Food Security, Improved Nutrition and Affordable Healthy Diets for All." Rome, FAO: FAO, IFAD, UNICEF, WFP and WHO. https://doi.org/10.4060/cb4474en.

FEWS NET. 2021a. “COVID-19 Pandemic Impacts on Food Security.” COVID-19 Pandemic Impacts on Food Security. 2021. https://fews.net/covid-19-pandemic-impacts-food-security.

———. 2021b. “Price Watch, April 2021.” Famine Early Warning Systems Network Price Watch. Washington D.C: USAID. https://fews.net/sites/default/files/documents/reports/PW_Global_202105_FINAL.pdf.

Food Security Information Network. 2021. “2021 Global Report on Food Crises - Joint Analysis for Better Decisions.” Global Report on Food Crises. New York: United Nations. https://docs.wfp.org/api/documents/WFP-0000127413/download/?_ga=2.146781172.1578338348.1623780805-1482088016.1620667102.

Food Security Information Network, and Global Network Against Food Crises. 2021. “Global Report on Food Crises 2021.” Rome. https://www.wfp.org/publications/global-report-food-crises-2021.

Fuentes, Natalia Martín, and Isabella Moder. 2021. “The Scarring Effects of COVID-19 on the Global Economy.” *VoxEU.Org* (blog). February 5, 2021. https://voxeu.org/article/scarring-effects-covid-19-global-economy.

Furceri, Davide, Prakash Loungani, Jonathan D. Ostry, and Pietro Pizzuto. 2020. “COVID-19 Will Raise Inequality If Past Pandemics Are a Guide.” *VoxEU.Org* (blog). May 8, 2020. https://voxeu.org/article/covid-19-will-raise-inequality-if-past-pandemics-are-guide.

Gakidou, Emmanuela, Krycia Cowling, Rafael Lozano, and Christopher JL Murray. 2010. “Increased Educational Attainment and Its Effect on Child Mortality in 175 Countries between 1970 and 2009: A Systematic Analysis.” *The Lancet* 376 (9745): 959–74. https://doi.org/10.1016/S0140-6736(10)61257-3.

Gates, Scott, Håvard Hegre, Håvard Mokleiv Nygård, and Håvard Strand. 2012a. “Development Consequences of Armed Conflict.” *World Development* 40 (9): 1713–22. https://doi.org/10.1016/j.worlddev.2012.04.031.

———. 2012b. “Development Consequences of Armed Conflict.” *World Development* 40 (9): 1713–22. https://doi.org/10.1016/j.worlddev.2012.04.031.

Ghobarah, Hazem Adam, Paul Huth, and Bruce Russett. 2003. “Civil Wars Kill and Maim People—Long After the Shooting Stops.” *American Political Science Review* 97 (2): 189–202. https://doi.org/10.1017/S0003055403000613.

Gleditsch, Nils Petter. 2012. “Whither the Weather? Climate Change and Conflict.” *Journal of Peace Research* 49 (1). https://www.prio.org/Publications/Publication/?x=5181.

Global Trade Analysis Project. 2018. “GTAP 9 Database.” https://www.gtap.agecon.purdue.edu/databases/v9/default.asp.

Grimard, F., and S. Laszlo. 2014. “Long-Term Effects of Civil Conflict on Women’s Health Outcomes in Peru.” *World Development* 54 (February): 139–55. https://doi.org/10.1016/j.worlddev.2013.08.004.

Hallegatte, Stephane, Mook Bangalore, Laura Bonzanigo, Marianne Fay, Tamaro Kane, Ulf Narloch, Julie Rozenberg, David Treguer, and Adrien Vogt-Schilb. 2016. *Shock Waves: Managing the Impacts of Climate Change on Poverty*. Climate Change and Development. World Bank Group. https://openknowledge.worldbank.org/bitstream/handle/10986/22787/9781464806735.pdf?sequence=13&isAllowed=y.

Hallegatte, Stephane, Mook Bangalore, Laura Bonzanigo, Marianne Fay, Ulf Narloch, Julie Rozenberg, and Adrien Vogt-Schilb. 2014. *Climate Change and Poverty—An Analytical Framework*. Policy Research Working Papers. The World Bank. https://doi.org/10.1596/1813-9450-7126.

Hallegatte, Stephane, Marianne Fay, and Edward Barbier. 2018. "Poverty and Climate Change: Introduction." *Environment and Development Economics*, no. 23: 217–33. https://doi.org/10.1017/S1355770X18000141.

Hanna, Taylor, David K. Bohl, Jonathan D. Moyer, and Michael D. Rafa. 2020. "Assessing the Impact of Conflict on Development in North-East Nigeria." Frederick S. Pardee Center for International Futures and United Nations Development Programme.

Hasegawa, Tomoko, Shinichiro Fujimori, Petr Havlík, Hugo Valin, Benjamin Leon Bodirsky, Jonathan C. Doelman, Thomas Fellmann, et al. 2018. "Risk of Increased Food Insecurity under Stringent Global Climate Change Mitigation Policy." *Nature Climate Change* 8 (8): 699–703. https://doi.org/10.1038/s41558-018-0230-x.

Hasegawa, Tomoko, Shinichiro Fujimori, Yonghee Shin, Akemi Tanaka, Kiyoshi Takahashi, and Toshihiko Masui. 2015. "Consequence of Climate Mitigation on the Risk of Hunger." *Environmental Science & Technology* 49 (12): 7245–53. https://doi.org/10.1021/es5051748.

Hasegawa, Tomoko, Shinichiro Fujimori, Kiyoshi Takahashi, and Toshihiko Masui. 2015. "Scenarios for the Risk of Hunger in the Twenty-First Century Using Shared Socioeconomic Pathways." *Environmental Research Letters* 10 (1): 014010. https://doi.org/10.1088/1748-9326/10/1/014010.

Headey, Derek D, and Harold H Alderman. 2019. "The Relative Caloric Prices of Healthy and Unhealthy Foods Differ Systematically across Income Levels and Continents." *The Journal of Nutrition* 149 (11): 2020–33. https://doi.org/10.1093/jn/nxz158.

Headey, Derek D., and Marie T. Ruel. 2020. "Economic Shocks and Child Wasting." 0 ed. Washington, DC: International Food Policy Research Institute. https://doi.org/10.2499/p15738coll2.133786.

Headey, Derek, Rebecca Heidkamp, Saskia Osendarp, Marie Ruel, Nick Scott, Robert Black, Meera Shekar, et al. 2020. "Impacts of COVID-19 on Childhood Malnutrition and Nutrition-Related Mortality." *The Lancet* 396 (10250): 519–21. https://doi.org/10.1016/S0140-6736(20)31647-0.

Hedden, Steve, Barry B. Hughes, Dale S. Rothman, Allana j. Markle, Joel Maweni, and Ibrahim Mayaki. 2016. "Eliminating Hunger in Africa - the Elimination of Hunger and Food Insecurity on the African Continent by 2025 - Conditions for Success." NEPAD. https://pardee.du.edu/ending-hunger-africa-elimination-hunger-and-food-insecurity-african-continent-2025-conditions.

Hegre, Håvard, Halvard Buhaug, Katherine V Calvin, Jonas Nordkvelle, Stephanie T Waldhoff, and Elisabeth Gilmore. 2016. "Forecasting Civil Conflict along the Shared Socioeconomic Pathways." *Environmental Research Letters* 11 (5): 054002. https://doi.org/10.1088/1748-9326/11/5/054002.

Hellberg, Rosalee, and Eric Chu. 2015. "Effects of Climate Change on the Persistence and Dispersal of Foodborne Bacterial Pathogens in the Outdoor Environment: A Review." *Critical Reviews in Microbiology* 42 (January). https://doi.org/10.3109/1040841X.2014.972335.

Herndon, Thomas, Michael Ash, and Robert Pollin. 2014. "Does High Public Debt Consistently Stifle Economic Growth? A Critique of Reinhart and Rogoff." *Cambridge Journal of Economics* 38 (2): 257–79. https://doi.org/10.1093/cje/bet075.

Higgins, Daniel, Tim Balint, Harold Liversage, and Paul Winters. 2018. "Investigating the Impacts of Increased Rural Land Tenure Security: A Systematic Review of the Evidence." *Journal of Rural Studies* 61: 34–62.

Hill, Ruth Vargas, and Ambar Narayan. 2020. "Covid-19 and Inequality: A Review of the Evidence on the Likely Impact and Policy Options." *Centre for Disaster Protection*, December, 28.

Hsiang, Solomon M., Marshall Burke, and Edward Miguel. 2013. "Quantifying the Influence of Climate on Human Conflict." *Science* 341 (6151). https://doi.org/10.1126/science.1235367.

Hughes, Barry B. 2019. *Exploring and Understanding International Futures: Building a Global Model System*. London: Elsevier.

Hughes, Barry B., Taylor Hanna, Kaylin McNeil, David K. Bohl, and Jonathan D. Moyer. 2021. "Pursuing the Sustainable Development Goals in a World Reshaped by COVID-19." New York, NY and Denver, CO: United Nations Development Programme and Frederick S. Pardee Center for International Futures.
https://sdgintegration.undp.org/sites/default/files/Foundational_research_report.pdf.

Hughes, Barry B., Devin K. Joshi, Jonathan D. Moyer, Timothy D. Sisk, and Jose R. Solorzano. 2014. *PPHP 5: Strengthening Governance Globally: Forecasting the next 50 Years*. Patterns of Potential Human Progress. Pardee Center for International Futures, University of Denver. https://pardee.du.edu/pphp-5-strengthening-governance-globally.

Hughes, Barry B., Devin K. Joshi, Jonathan D. Moyer, Timothy D. Sisk, and José R. Solórzano. 2014. "Strengthening Governance Globally: Forecasting the Next 50 Years." 5. Patterns of Potential Human Progress. Pardee Center for International Futures.

Hughes, Barry B., and Kanishka Narayan. 2021. "Enhancing Integrated Analysis of National and Global Goal Pursuit by Endogenizing Economic Productivity." *PLOS ONE* 16 (2): e0246797.
https://doi.org/10.1371/journal.pone.0246797.

Huicho, Luis, Elisa Vidal-Cárdenas, Nadia Akseer, Samanpreet Brar, Kaitlin Conway, Muhammad Islam, Elisa Juarez, et al. 2020. "Drivers of Stunting Reduction in Peru: A Country Case Study." *The American Journal of Clinical Nutrition* 112 (Supplement_2): 816S-829S.
https://doi.org/10.1093/ajcn/nqaa164.

Ibañez, A.M, and A. Moya. 2010. “Do Conflicts Create Poverty Traps? Asset Losses and Recovery for Displaced Households in Colombia.” In *The Economics of Crime: Lessons For and From Latin America*, edited by Rafael Di Tella, Sebastian Edwards, and Ernesto Schargrodsky, 137–70. University of Chicago Press.

Ide, Tobias, Janpeter Schilling, Jasmin S. A. Link, Jürgen Scheffran, Grace Ngaruiya, and Thomas Weinzierl. 2014. “On Exposure, Vulnerability and Violence: Spatial Distribution of Risk Factors for Climate Change and Violent Conflict across Kenya and Uganda.” *Political Geography*, Special Issue: Climate Change and Conflict, 43 (November): 68–81. https://doi.org/10.1016/j.polgeo.2014.10.007.

IHME. 2020. “COVID-19 Projections.” Institute for Health Metrics and Evaluation. 2020. https://covid19.healthdata.org/.

ILO. 2021. “ILO Monitor: COVID-19 and the World of Work. Seventh Edition: Updated Estimates and Analysis.” ILO Monitor. International Labour Organization. https://www.ilo.org/global/topics/coronavirus/impacts-and-responses/WCMS_767028/lang--en/index.htm.

IMF. 2020. “World Economic Outlook, April 2020: The Great Lockdown.” International Monetary Fund. https://www.imf.org/en/Publications/WEO/Issues/2020/04/14/weo-april-2020.

———. 2021a. “Fiscal Monitor: A Fair Shot.” Global Fiscal Monitor. IMF. https://www.imf.org/en/Publications/FM/Issues/2021/03/29/fiscal-monitor-april-2021.

———. 2021b. “World Economic Outlook, April 2021: Managing Divergent Recoveries.” World Economic Outlook. IMF. https://www.imf.org/en/Publications/WEO/Issues/2021/03/23/world-economic-outlook-april-2021.

IMF and World Bank. 2021. “Debt Sustainability Analysis.” Text/HTML. *Debt Sustainability Analysis for Low-Income Countries* (blog). 2021. https://www.worldbank.org/en/programs/debt-toolkit/dsa.

Intergovernmental Panel on Climate Change. 2007. “Climate Change: Impacts, Adaptation and Vulnerability, Contribution of Working Group II to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change.” Cambridge, UK: Cambridge Univ Press. https://www.ipcc.ch/report/ar4/wg2/.

International Trade Centre. 2020. “COVID-19 Temporary Trade Measures.” Market Access Map. July 2020. https://www.macmap.org/covid19.

Iram, Uzma, and Muhammad S. Butt. 2004. “Determinants of Household Food Security: An Empirical Analysis for Pakistan.” *International Journal of Social Economics* 31 (8): 753–66. https://doi.org/10.1108/03068290410546011.

Ittersum, Martin K. van, Lenny G. J. van Bussel, Joost Wolf, Patricio Grassini, Justin van Wart, Nicolas Guilpart, Lieven Claessens, et al. 2016. “Can Sub-Saharan Africa Feed Itself?” *Proceedings of the National Academy of Sciences* 113 (52): 14964–69. https://doi.org/10.1073/pnas.1610359113.

Janssens, Charlotte, Petr Havlík, Tamás Krisztin, Justin Baker, Stefan Frank, Tomoko Hasegawa, David Leclère, et al. 2020a. "Global Hunger and Climate Change Adaptation through International Trade." *Nature Climate Change* 10 (9): 829–35. https://doi.org/10.1038/s41558-020-0847-4.

———. 2020b. "Global Hunger and Climate Change Adaptation through International Trade." *Nature Climate Change* 10 (9): 829–35. https://doi.org/10.1038/s41558-020-0847-4.

Joshi, Devin K., Barry B. Hughes, and Timothy D. Sisk. 2015. "Improving Governance for the Post-2015 Sustainable Development Goals: Scenario Forecasting the Next 50years." *World Development* 70 (June): 286–302. https://doi.org/10.1016/j.worlddev.2015.01.013.

Justino, Patricia. 2012. "War and Poverty." *IDS Working Papers* 2012 (391): 1–29. https://doi.org/10.1111/j.2040-0209.2012.00391.x.

Kaffenberger, Michelle. 2021. "Modelling the Long-Run Learning Impact of the Covid-19 Learning Shock: Actions to (More than) Mitigate Loss." *International Journal of Educational Development* 81 (March). https://doi.org/10.1016/j.ijedudev.2020.102326.

Khara, Tanya, Martha Mwangome, Moses Ngari, and Carmel Dolan. 2018. "Children Concurrently Wasted and Stunted: A Meta-Analysis of Prevalence Data of Children 6–59 Months from 84 Countries." *Maternal and Child Nutrition* 14 (2): e12516. https://doi.org/10.1111/mcn.12516.

Kharas, Homi, and Kristofer Hamel. 2020. "Turning Back the Poverty Clock: How Will COVID-19 Impact the World's Poorest People?" *Brookings* (blog). May 6, 2020. https://www.brookings.edu/blog/future-development/2020/05/06/turning-back-the-poverty-clock-how-will-covid-19-impact-the-worlds-poorest-people/.

Kjellstrom, Tord, R. Sari Kovats, Simon J. Lloyd, Tom Holt, and Richard S. J. Tol. 2009. "The Direct Impact of Climate Change on Regional Labor Productivity." *Archives of Environmental & Occupational Health* 64 (4): 217–27. https://doi.org/10.1080/19338240903352776.

Kogo, Benjamin Kipkemboi, Lalit Kumar, and Richard Koech. 2021. "Climate Change and Variability in Kenya: A Review of Impacts on Agriculture and Food Security." *Environment, Development and Sustainability* 23 (1): 23–43. https://doi.org/10.1007/s10668-020-00589-1.

Kolstad, Erik W., and Kjell Arne Johansson. 2011. "Uncertainties Associated with Quantifying Climate Change Impacts on Human Health: A Case Study for Diarrhea." *Environmental Health Perspectives* 119 (3): 299–305. https://doi.org/10.1289/ehp.1002060.

Koubi, Vally. 2019. "Climate Change and Conflict." *Annual Review of Political Science*, May. https://doi.org/10.1146/annurev-polisci-050317-070830.

Laborde, David, Will Martin, Johan Swinnen, and Rob Vos. 2020. "COVID-19 Risks to Global Food Security." *Science* 369 (6503): 500–502. https://doi.org/10.1126/science.abc4765.

Laborde, David, Will Martin, and Rob Vos. 2021. "Impacts of COVID-19 on Global Poverty, Food Security, and Diets: Insights from Global Model Scenario Analysis." *Agricultural Economics*, 1–16. https://doi.org/10.1111/agec.12624.

Lai, Brian, and Clayton Thyne. 2007. "The Effect of Civil War on Education, 1980-97." *Journal of Peace Research* 44 (3): 277–92.

Leroy, Jef L, and Edward A Frongillo. 2019. "Perspective: What Does Stunting Really Mean? A Critical Review of the Evidence." *Advances in Nutrition* 10 (2): 196–204. https://doi.org/10.1093/advances/nmy101.

Li, Zhihui, Rockli Kim, Sebastian Vollmer, and S. V. Subramanian. 2020. "Factors Associated With Child Stunting, Wasting, and Underweight in 35 Low- and Middle-Income Countries." *JAMA Network Open* 3 (4): e203386. https://doi.org/10.1001/jamanetworkopen.2020.3386.

Liu, Bing, Senthold Asseng, Christoph Müller, Frank Ewert, Joshua Elliott, David B. Lobell, Pierre Martre, et al. 2016. "Similar Estimates of Temperature Impacts on Global Wheat Yield by Three Independent Methods." *Nature Climate Change* 6 (12): 1130–36. https://doi.org/10.1038/nclimate3115.

Lloyd, Simon J., Mook Bangalore, Zaid Chalabi, R. Sari Kovats, Stèphane Hallegatte, Julie Rozenberg, Hugo Valin, and Petr Havlík. 2018. "A Global-Level Model of the Potential Impacts of Climate Change on Child Stunting via Income and Food Price in 2030." *Environmental Health Perspectives* 126 (9): 97007. https://doi.org/10.1289/EHP2916.

Mahler, Daniel G, Nishant Yonzan, Christoph Lakner, R. Andres Castaneda Aguilar, and Haoyu Wu. 2021. "Updated Estimates of the Impact of COVID-19 on Global Poverty: Turning the Corner on the Pandemic in 2021?" *World Bank Blogs* (blog). June 24, 2021. https://blogs.worldbank.org/opendata/updated-estimates-impact-covid-19-global-poverty-turning-corner-pandemic-2021.

Marks, Zoe. 2016. "Poverty and Conflict." 52. Professional Development Reading Pack. GSDRC. https://assets.publishing.service.gov.uk/media/5980670a40f0b61e4b00003e/Poverty-and-conflict_RP.pdf.

Martin-Shields, Charles P., and Wolfgang Stojetz. 2019. "Food Security and Conflict: Empirical Challenges and Future Opportunities for Research and Policy Making on Food Security and Conflict." *World Development* 119 (July): 150–64. https://doi.org/10.1016/j.worlddev.2018.07.011.

Mbow, C, C Rosenzweig, L.G Barioni, T.G Benton, M Herrero, M Krishnapillai, E Liwenga, et al. 2019. "Food Security." In *Climate Change and Land: An IPCC Special Report on Climate Change, Desertification, Land Degradation, Sustainable Land Management, Food Security, and Greenhouse Gas Fluxes in Terrestrial Ecosystems*, edited by P.R Shukla, J Skea, E Calvo Buendia, V Masson-Delmotte, H.O Pörtner, D.C Roberts, P Zhai, et al.

Mcgrath, Justin M., and David B. Lobell. 2013. "Reduction of Transpiration and Altered Nutrient Allocation Contribute to Nutrient Decline of Crops Grown in Elevated CO_2 Concentrations." *Plant, Cell & Environment* 36 (3): 697–705. https://doi.org/10.1111/pce.12007.

Meijl, Hans van, Lindsay Shutes, Hugo Valin, Elke Stehfest, Michiel van Dijk, Marijke Kuiper, Andrzej Tabeau, Willem-Jan van Zeist, Tomoko Hasegawa, and Petr Havlik. 2020. "Modelling Alternative

Futures of Global Food Security: Insights from FOODSECURE." *Global Food Security* 25 (June): 100358. https://doi.org/10.1016/j.gfs.2020.100358.

Messer, E, and Marc J. Cohen. 2015. "Breaking the Links Between Conflict and Hunger Redux." *World Medical & Health Policy* 7 (3): 211–33. https://doi.org/10.1002/wmh3.147.

Messer, E, Marc J. Cohen, and Jashinta D'Costa. 1998. "Food from Peace: Breaking the Links between Conflict and Hunger." 24. *2020 Vision Discussion Papers*. 2020 Vision Discussion Papers. International Food Policy Research Institute. https://ideas.repec.org/p/fpr/2020dp/24.html.

Milante, Gary, Barry B. Hughes, and Alison Burt. 2016. "Poverty Eradication in Fragile Places: Prospects for Harvesting the Highest Hanging Fruit by 2030." *Stability: International Journal of Security and Development* 5 (1): 7. https://doi.org/10.5334/sta.435.

Moran, Ashley, Joshua Busby, Todd G. Smith, Nisha Krishnan, and Charles Wight. 2018. "The Intersection of Global Fragility and Climate Risk." USAID.

Moyer, Jonathan D, David Bohl, Taylor Hanna, Brendan R Mapes, and Mickey Rafa. 2019. "Assessing the Impact of War on Development in Yemen." Denver, CO and New York, NY: Frederick S. Pardee Center for International Futures and Josef Korbel School of International Studies and United Nations Development Programme. https://pardee.du.edu/sites/default/files/UNDP-Y_FullReport_WEB.pdf.

Moyer, Jonathan D., and David K. Bohl. 2018. "Alternative Pathways to Human Development: Assessing Trade-Offs and Synergies in Achieving the Sustainable Development Goals." *Futures*, November. https://doi.org/10.1016/j.futures.2018.10.007.

Moyer, Jonathan D., David K. Bohl, Caleb Petry, Andrew Scott, José R. Solórzano, and Randall Kuhn. 2020. "The Persistent Global Burden of Severe Acute Malnutrition: Cross-Country Estimates, Models and Forecasts." *Global Transitions* 2 (January): 167–79. https://doi.org/10.1016/j.glt.2020.07.004.

Moyer, Jonathan D, Taylor Hanna, David K Bohl, and Brendan R Mapes. 2019. "Assessing the Impact of War in Yemen on Achieving the Sustainable Development Goals." Invited Research Paper. Denver, CO: Report for UNDP by the Frederick S. Pardee Center for International Futures, Josef Korbel School of International Studies. https://reliefweb.int/sites/reliefweb.int/files/resources/UNDP-YEM%20War%20Impact%20on% 20SDGs_compressed.pdf.

———. n.d. "ASSESSING THE IMPACT OF WAR IN YEMEN," 78.

Moyer, Jonathan D., and Steve Hedden. 2020. "Are We on the Right Path to Achieve the Sustainable Development Goals?" *World Development* 127 (March): 104749. https://doi.org/10.1016/j.worlddev.2019.104749.

Moyer, Jonathan D., and Oliver Kaplan. 2020. "Will the Coronavirus Fuel Conflict?" *Foreign Policy* (blog). July 2020. https://foreignpolicy.com/2020/07/06/coronavirus-pandemic-fuel-conflict-fragile-states-economy-food-prices/.

Mueller, Hannes, and Chanon Techasunthornwat. 2020. "Conflict and Poverty." *Policy Research Working Paper*, Poverty and Shared Prosperity, 9455 (October). https://documents1.worldbank.org/curated/en/519741603804458786/pdf/Conflict-and-Poverty.pdf.

Mueller, Nathaniel D., James S. Gerber, Matt Johnston, Deepak K. Ray, Navin Ramankutty, and Jonathan A. Foley. 2012. "Closing Yield Gaps through Nutrient and Water Management." *Nature* 490 (7419): 254–57. https://doi.org/10.1038/nature11420.

Müller, Marc F., Gopal Penny, Meredith T. Niles, Vincent Ricciardi, Davide Danilo Chiarelli, Kyle Frankel Davis, Jampel Dell'Angelo, et al. 2021. "Impact of Transnational Land Acquisitions on Local Food Security and Dietary Diversity." *Proceedings of the National Academy of Sciences* 118 (4). https://doi.org/10.1073/pnas.2020535118.

Nelson, G.C, M.W Rosegrant, A Palazzo, I Gray, C Ingersoll, R.D Robertson, S Tokgoz, et al. 2010. "Food Security, Farming, and Climate Change to 2050." International Food Policy Research Institute. https://doi.org/10.2499/9780896291867.

Neumann, Kathleen, Peter H. Verburg, Elke Stehfest, and Christoph Müller. 2010. "The Yield Gap of Global Grain Production: A Spatial Analysis." *Agricultural Systems* 103 (5): 316–26. https://doi.org/10.1016/j.agsy.2010.02.004.

Nordhaus, William. 2018. "Projections and Uncertainties about Climate Change in an Era of Minimal Climate Policies." *American Economic Journal: Economic Policy* 10 (3): 333–60.

OECD and FAO. 2020. *OECD-FAO Agricultural Outlook 2020-2029*. OECD-FAO Agricultural Outlook 2020. Rome, Italy: FAO and OECD. https://doi.org/10.1787/1112c23b-enAlso Available in: Chinese Spanish French.

O'Neill, Brian C., Elmar Kriegler, Keywan Riahi, Kristie L. Ebi, Stephane Hallegatte, Timothy R. Carter, Ritu Mathur, and Detlef P. van Vuuren. 2014. "A New Scenario Framework for Climate Change Research: The Concept of Shared Socioeconomic Pathways." *Climatic Change* 122 (3): 387–400. https://doi.org/10.1007/s10584-013-0905-2.

Onis, Mercedes, and Francesco Branca. 2016. "Childhood Stunting: A Global Perspective." *Maternal & Child Nutrition* 12 (May): 12–26. https://doi.org/10.1111/mcn.12231.

Osendarp, Saskia, Jonathan Kweku Akuoku, Robert E. Black, Derek Headey, Marie Ruel, Nick Scott, Meera Shekar, et al. 2021. "The COVID-19 Crisis Will Exacerbate Maternal and Child Undernutrition and Child Mortality in Low- and Middle-Income Countries." *Nature Food* 2 (7): 476–84. https://doi.org/10.1038/s43016-021-00319-4.

Østby, Gudrun, Henrik Urdal, Mohammad Zulfan Tadjoeddin, S. Mansoob Murshed, and Håvard Strand. 2011. "Population Pressure, Horizontal Inequality and Political Violence: A Disaggregated Study of Indonesian Provinces, 1990–2003." *The Journal of Development Studies* 47 (3): 377–98. https://doi.org/10.1080/00220388.2010.506911.

Owoo, Nkechi S., and Louis Boakye-Yiadom. 2015. "The Gender Dimension of the Effects of Land Tenure Security on Agricultural Productivity: Some Evidence from Two Districts in Kenya." *Journal of International Development* 27 (7): 917–28. https://doi.org/10.1002/jid.3028.

Perpiña Castillo, Carolina, Chris Jacobs-Crisioni, Vasco Diogo, and Carlo Lavalle. 2021. "Modelling Agricultural Land Abandonment in a Fine Spatial Resolution Multi-Level Land-Use Model: An Application for the EU." *Environmental Modelling & Software* 136 (February): 104946. https://doi.org/10.1016/j.envsoft.2020.104946.

Phalan, Ben, Malvika Onial, Andrew Balmford, and Rhys E. Green. 2011. "Reconciling Food Production and Biodiversity Conservation: Land Sharing and Land Sparing Compared." *Science* 333 (6047): 1289–91. https://doi.org/10.1126/science.1208742.

Pittelkow, Cameron M., Xinqiang Liang, Bruce A. Linquist, Kees Jan van Groenigen, Juhwan Lee, Mark E. Lundy, Natasja van Gestel, Johan Six, Rodney T. Venterea, and Chris van Kessel. 2015. "Productivity Limits and Potentials of the Principles of Conservation Agriculture." *Nature* 517 (7534): 365–68. https://doi.org/10.1038/nature13809.

Ragasa, Catherine, Isabel Lambrecht, Kristi Mahrt, Zin Wai Aung, and Michael Wang. 2021. "Immediate Impacts of COVID-19 on Female and Male Farmers in Central Myanmar: Phone-Based Household Survey Evidence." *Agricultural Economics* 52 (3): 505–23. https://doi.org/10.1111/agec.12632.

Raleigh, Clionadh. 2010. "Political Marginalization, Climate Change, and Conflict in African Sahel States." *International Studies Review* 12 (1): 69–86.

Raleigh, Clionadh, and Henrik Urdal. 2007. "Climate Change, Environmental Degradation and Armed Conflict." *Political Geography*, Climate Change and Conflict, 26 (6): 674–94. https://doi.org/10.1016/j.polgeo.2007.06.005.

Ramsey, A. Ford, Barry K. Goodwin, William F. Hahn, and Matthew T. Holt. 2021. "Impacts of COVID-19 and Price Transmission in U.S. Meat Markets." *Agricultural Economics* 52 (3): 441–58. https://doi.org/10.1111/agec.12628.

Reinhart, Carmen M., and Kenneth S. Rogoff. 2010. "Growth in a Time of Debt." w15639. National Bureau of Economic Research. https://doi.org/10.3386/w15639.

———. 2011. *This Time Is Different: Eight Centuries of Financial Folly*. Reprint edition. Princeton: Princeton University Press.

Ricciardi, Vincent, Navin Ramankutty, Zia Mehrabi, Larissa Jarvis, and Brenton Chookolingo. 2018. "How Much of the World's Food Do Smallholders Produce?" *Global Food Security* 17 (June): 64–72. https://doi.org/10.1016/j.gfs.2018.05.002.

Roberton, Timothy, Emily D Carter, Victoria B Chou, Angela R Stegmuller, Bianca D Jackson, Yvonne Tam, Talata Sawadogo-Lewis, and Neff Walker. 2020. "Early Estimates of the Indirect Effects of the COVID-19 Pandemic on Maternal and Child Mortality in Low-Income and Middle-Income Countries: A Modelling Study." *The Lancet Global Health* 8 (7): e901–8. https://doi.org/10.1016/S2214-109X(20)30229-1.

Rockmore, M. 2015. "Conflict and Agricultural Portfolios Evidence from Northern Uganda." *Working Paper*.

Rodriguez-Oreggia, Eduardo, Alejandro De La Fuente, Rodolfo De La Torre, and Hector A Moreno. 2013. "Natural Disasters, Human Development and Poverty at the Municipal Level in Mexico." *Journal of Development Studies* 49 (3): 442–55.

Rohwerder, Brigitte. 2014. "The Impact of Conflict on Poverty." Helpdesk Research Report. GSDRC. http://www.gsdrc.org/docs/open/hdq1118.pdf.

Rosenzweig, Cynthia, Joshua Elliott, Delphine Deryng, Alex C. Ruane, Christoph Müller, Almut Arneth, Kenneth J. Boote, et al. 2014. "Assessing Agricultural Risks of Climate Change in the 21st Century in a Global Gridded Crop Model Intercomparison." *Proceedings of the National Academy of Sciences* 111 (9): 3268–73. https://doi.org/10.1073/pnas.1222463110.

RTAC and USAID. 2020. "Policy Recommendations for Strengthening Resilience and Self-Sufficiency Among Refugees in Protracted Camps and Their Hosts." USAID and RTAC.

"Rwanda: The Impact of Conflict on Growth and Poverty." 2004. Social Development Notes 18. Conflict Prevention & Reconstruction. The World Bank. https://openknowledge.worldbank.org/bitstream/handle/10986/11268/293530RW0confl10CPR0no101801Public1.pdf?sequence=1.

Ryan, Sadie J., Catherine A. Lippi, and Fernanda Zermoglio. 2020. "Shifting Transmission Risk for Malaria in Africa with Climate Change: A Framework for Planning and Intervention." *Malaria Journal* 19 (1): 170. https://doi.org/10.1186/s12936-020-03224-6.

Salehyan, Idean. 2008. "From Climate Change to Conflict? No Consensus Yet." *Journal of Peace Research - J PEACE RES* 45 (May): 315–26. https://doi.org/10.1177/0022343308088812.

Schmidhuber, Josef, and Francesco N. Tubiello. 2007. "Global Food Security under Climate Change." *Proceedings of the National Academy of Sciences of the United States of America* 104 (50): 19703–8. https://doi.org/10.1073/pnas.0701976104.

Schmidt, Emily, Paul Dorosh, and Rachel Gilbert. 2021. "Impacts of COVID-19 Induced Income and Rice Price Shocks on Household Welfare in Papua New Guinea: Household Model Estimates." *Agricultural Economics* 52 (3): 391–406. https://doi.org/10.1111/agec.12625.

Schoenbuchner, Simon M, Carmel Dolan, Martha Mwangome, Andrew Hall, Stephanie A Richard, Jonathan C Wells, Tanya Khara, Bakary Sonko, Andrew M Prentice, and Sophie E Moore. 2019. "The Relationship between Wasting and Stunting: A Retrospective Cohort Analysis of Longitudinal Data in Gambian Children from 1976 to 2016." *The American Journal of Clinical Nutrition* 110 (2): 498–507. https://doi.org/10.1093/ajcn/nqy326.

Schwartzstein, Peter. 2019. "One of Africa's Most Fertile Lands Is Struggling to Feed Its Own People." *Bloomberg*, April 2, 2019. https://www.bloomberg.com/features/2019-sudan-nile-land-farming/.

Serrano, Alexander, and Daniela Gutierrez Torres. 2020. "Latin America Moving Fast to Ensure Water Services during COVID-19." 2020. https://blogs.worldbank.org/water/latin-america-moving-fast-ensure-water-services-during-covid-19.

Shorrocks, Anthony, and Guanghua Wan. 2008. "Ungrouping Income Distributions: Synthesising Samples for Inequality and Poverty Analysis." Research Paper 2008/16. Helsinki: UNU-WIDER. http://www.wider.unu.edu/publications/working-papers/research-papers/2008/en_GB/rp2008-16/_files/78941482225631708/default/rp2008-16.pdf.

Singhal, Saurabh. 2019. "Early Life Shocks and Mental Health: The Long-Term Effect of War in Vietnam." *Journal of Development Economics* 141 (November): 102244. https://doi.org/10.1016/j.jdeveco.2018.06.002.

Skoufias, Emmanuel, Mariano Rabassa, and Sergio Olivieri. 2011. *The Poverty Impacts of Climate Change A Review of the Evidence*. Vol. 1. Policy Research Working Papers. The World Bank. http://documents.worldbank.org/curated/en/712691468042044435/The-poverty-impacts-of-climate-change-a-review-of-the-evidence.

Stewart, Christine P., Lora Iannotti, Kathryn G. Dewey, Kim F. Michaelsen, and Adelheid W. Onyango. 2013. "Contextualising Complementary Feeding in a Broader Framework for Stunting Prevention." *Maternal & Child Nutrition* 9 (S2): 27–45. https://doi.org/10.1111/mcn.12088.

Stewart, Frances. 2005. "Horizontal Inequalities: A Neglected Dimension of Development." In *Wider Perspectives on Global Development*, edited by Anthony B. Atkinson, Kaushik Basu, Jagdish N. Bhagwati, Douglass C. North, Dani Rodrik, Frances Stewart, Joseph E. Stiglitz, and Jeffrey G. Williamson, 101–35. Studies in Development Economics and Policy. London: Palgrave Macmillan UK. https://doi.org/10.1057/9780230501850_5.

Sulser, Timothy B., Daniel Mason D'Croz, Shahnila Islam, Sherman Robinson, Keith Wiebe, and M.W Rosegrant. 2015. "Africa in the Global Agricultural Economy in 2030 and 2050. Beyond a Middle-Income Africa: Transforming African Economies for Sustained Growth with Rising Employment and Incomes." Washington D.C.: International Food Policy Research Institute. http://www.fao.org/family-farming/detail/en/c/383681/.

Sumner, Andy, Chris Hoy, and Eduardo Ortiz-Juarez. 2020. "Estimates of the Impact of COVID-19 on Global Poverty." WIDER Working Paper 2020/43. UNU-WIDER. https://doi.org/10.35188/UNU-WIDER/2020/800-9.

Swinnen, Johan. 2020. "COVID-19 Is Exacerbating Inequalities in Food Security." 0 ed. Washington, DC: International Food Policy Research Institute. https://doi.org/10.2499/p15738coll2.133762_03.

Swinnen, Johan, and Rob Vos. 2021. "COVID-19 and Impacts on Global Food Systems and Household Welfare: Introduction to a Special Issue." *Agricultural Economics* 52 (3): 365–74. https://doi.org/10.1111/agec.12623.

Szabo, Sylvia. 2016. "Urbanisation and Food Insecurity Risks: Assessing the Role of Human Development." *Oxford Development Studies* 44 (1): 28–48. https://doi.org/10.1080/13600818.2015.1067292.

Tai, Amos P. K., Maria Val Martin, and Colette L. Heald. 2014. "Threat to Future Global Food Security from Climate Change and Ozone Air Pollution." *Nature Climate Change* 4 (9): 817–21. https://doi.org/10.1038/nclimate2317.

Teodosijevic, S.B. 2003. "Armed Conflicts and Food Security." *Working Paper*. https://doi.org/10.22004/ag.econ.289088.

The Land Matrix. 2021. "The Land Matrix." https://landmatrix.org/list/deals.

The World Bank Group. 2020. "WASH (Water, Sanitation & Hygiene) and COVID-19." Text/HTML. World Bank. April 6, 2020. https://www.worldbank.org/en/topic/water/brief/wash-water-sanitation-hygiene-and-covid-19.

Tscharntke, Teja, Yann Clough, Thomas C. Wanger, Louise Jackson, Iris Motzke, Ivette Perfecto, John Vandermeer, and Anthony Whitbread. 2012. "Global Food Security, Biodiversity Conservation and the Future of Agricultural Intensification." *Biological Conservation*, ADVANCING ENVIRONMENTAL CONSERVATION: ESSAYS IN HONOR OF NAVJOT SODHI, 151 (1): 53–59. https://doi.org/10.1016/j.biocon.2012.01.068.

UN Human Rigths Council. 2020. "'There Is Nothing Left for Us': Starvation as a Method of Warfare in South Sudan." Conference room paper of the Commission on Human Rights in South Sudan. Human Rights Council. https://t.co/QsyFyOz3NG?amp=1.

UN Convention to Combat Desertification. 2017. "Global Land Outlook, First Edition." Bonn, Germany: UN Convention to Combat Desertification. https://knowledge.unccd.int/sites/default/files/2018-06/GLO percent20English_Full_Report_rev1.pdf.

UNESCO. 2020. "How Many Students Are at Risk of Not Returning to School?" UNESCO COVID-19 education response. https://unesdoc.unesco.org/in/documentViewer.xhtml?v=2.1.196&id=p::usmarcdef_0000373992&file=/in/rest/annotationSVC/DownloadWatermarkedAttachment/attach_import_5b075951-5390-4056-9935-4163d073d5f1%3F_%3D373992eng.pdf&locale=en&multi=true&ark=/ark:/48223/pf0000373992/PDF/373992eng.pdf#%5B%7B%22num%22%3A31%2C%22gen%22%3A0%7D%2C%7B%22name%22%3A%22XYZ%22%7D%2C63%2C777%2C0%5D.

———. 2021. "UNESCO Figures Show Two Thirds of an Academic Year Lost on Average Worldwide Due to Covid-19 School Closures." UNESCO. March 1, 2021. https://en.unesco.org/news/unesco-figures-show-two-thirds-academic-year-lost-average-worldwide-due-covid-19-school.

UNICEF, WHO, and World Bank Group. 2020. "Levels and Trends in Child Malnutrition: Key Findings of the 2020 Edition of the Joint Child Malnutrition Estimates." Joint Child Malnutrition Estimates. Geneva, Switzerland: WHO. https://www.who.int/publications-detail-redirect/jme-2020-edition.

———. 2021. "Levels and Trends in Child Malnutrition." Joint Child Malnutrition Estimates. New York, NY: WHO. file:///C:/Users/WILLEM~1.VER/AppData/Local/Temp/9789240025257-eng.pdf.

United Nations Security Council. 2002. “Report of the Secretary-General on Women, Peace and Security.” United Nations. http://www.un.org/womenwatch/ods/S-2002-1154-E.pdf. Accessed 10 Feb 2017.

Vaivada, Tyler, Nadia Akseer, Selai Akseer, Ahalya Somaskandan, Marianne Stefopulos, and Zulfiqar A Bhutta. 2020. “Stunting in Childhood: An Overview of Global Burden, Trends, Determinants, and Drivers of Decline.” *The American Journal of Clinical Nutrition* 112 (Supplement_2): 777S-791S. https://doi.org/10.1093/ajcn/nqaa159.

Van Hoyweghen, Kaat, Anna Fabry, Hendrik Feyaerts, Idrissa Wade, and Miet Maertens. 2021. “Resilience of Global and Local Value Chains to the Covid-19 Pandemic: Survey Evidence from Vegetable Value Chains in Senegal.” *Agricultural Economics* 52 (3): 423–40. https://doi.org/10.1111/agec.12627.

Verhagen, Willem, David K. Bohl, Jakkie Cilliers, Barry B. Hughes, Stellah Kwasi, Kaylin McNeil, Marius Oosthuizen, et al. 2021. “Analysing Long-Term Socio-Economic Impacts of COVID-19 across Diverse African Contexts.” New York, NY: UNDP Regional Bureau for Africa. https://www.africa.undp.org/content/rba/en/home/library/-long-term-socio-economic-impacts-of-covid-19-in-african-context.html.

Verhagen, Willem, Emma H. van der Zanden, Michael Strauch, Astrid J. A. van Teeffelen, and Peter H. Verburg. 2018. “Optimizing the Allocation of Agri-Environment Measures to Navigate the Trade-Offs between Ecosystem Services, Biodiversity and Agricultural Production.” *Environmental Science & Policy* 84 (June): 186–96. https://doi.org/10.1016/j.envsci.2018.03.013.

Verwimp, Philip, and Juan Carlos Muñoz-Mora. 2013. “Returning Home after Civil War: Food Security, Nutrition and Poverty among Burundian Households.” HiCN Working Paper 123. Households in Conflict Network. https://econpapers.repec.org/paper/hicwpaper/123.htm.

———. 2018. “Returning Home after Civil War: Food Security and Nutrition among Burundian Households.” *The Journal of Development Studies* 54 (6): 1019–40. https://doi.org/10.1080/00220388.2017.1311407.

Vilar-Compte, Mireya, Sebastian Sandoval-Olascoaga, Ana Bernal-Stuart, Sandhya Shimoga, and Arturo Vargas-Bustamante. 2015. “The Impact of the 2008 Financial Crisis on Food Security and Food Expenditures in Mexico: A Disproportionate Effect on the Vulnerable.” *Public Health Nutrition* 18 (16): 2934–42. https://doi.org/10.1017/S1368980014002493.

Vuuren, Detlef P. van, Jae Edmonds, Mikiko Kainuma, Keywan Riahi, Allison Thomson, Kathy Hibbard, George C. Hurtt, et al. 2011. “The Representative Concentration Pathways: An Overview.” *Climatic Change* 109 (1): 5. https://doi.org/10.1007/s10584-011-0148-z.

Wang, Huan, Sarah-Eve Dill, Huan Zhou, Yue Ma, Hao Xue, Sean Sylvia, Kumi Smith, et al. 2021. “Health, Economic, and Social Implications of COVID-19 for China’s Rural Population.” *Agricultural Economics* 52 (3): 495–504. https://doi.org/10.1111/agec.12630.

WFP, World Food Programme. 2020. “2020 - Global Report on Food Crises |.” WFP World Food Programme. https://www.wfp.org/publications/2020-global-report-food-crises.

WHO. 2010. *Nutritional Landscape Information System (NLIS) Country Profile Indicators Interpretation Guide*. Geneva, Switzerland. https://www.who.int/nutrition/nlis_interpretation_guide.pdf.

———. 2019. "WHO | Management of Infants under 6 Months of Age with Severe Acute Malnutrition." Factsheet. WHO. World Health Organization. February 11, 2019. http://www.who.int/elena/titles/sam_infants/en/.

WHO and UNICEF. 2009. *WHO Child Growth Standards and the Identification of Severe Acute Malnutrition in Infants and Children*. Geneva, Switzerland and New York, NY. https://www.who.int/nutrition/publications/severemalnutrition/9789241598163/en/.

World Bank. 2004. "Rwanda: The Impact of Conflict on Growth and Poverty." Social Development Notes. Conflict Prevention & Reconstruction. https://openknowledge.worldbank.org/bitstream/handle/10986/11268/293530RW0confl10CPR0no10 1801Public1.pdf?sequence=1&isAllowed=y.

———. 2019. "World Development Indicators | The World Bank." 2019. http://wdi.worldbank.org/table/4.2.

———. 2020a. "Global Indicators of Regulatory Governance." Text/HTML. World Bank. 2020. https://rulemaking.worldbank.org/en/explorecountries.

———. 2020b. "Tackling COVID-19 (Coronavirus) with Water, Sanitation and Hygiene in DRC." Text/HTML. World Bank. 2020. https://www.worldbank.org/en/news/feature/2020/04/20/tackling-covid-19-coronavirus-with-water-sanitation-and-hygiene-in-drc.

———. 2020c. "World Bank Education and COVID-19." Text/HTML. World Bank. April 30, 2020. https://www.worldbank.org/en/data/interactive/2020/03/24/world-bank-education-and-covid-19.

———. 2020d. "Monitoring COVID-19 Impact on Nigerian Households." Text/HTML. World Bank. July 9, 2020. https://www.worldbank.org/en/country/nigeria/brief/monitoring-covid-19-impact-on-nigerian-households.

———. 2021a. "Food Security and COVID-19." Text/HTML. World Bank. 2021. https://www.worldbank.org/en/topic/agriculture/brief/food-security-and-covid-19.

———. 2021b. "Global Economic Prospects. June 2021." Washington D.C. doi:10.1596/978-1-4648-1665-9.

———. 2021c. "Global Economic Prospects. Chapter 3: Global Economy Heading into a Decade of Disappointment?" Global Economic Prospect. https://pubdocs.worldbank.org/en/745401599838753479/Global-Economic-Prospects-January-2021-Topical-Issue-1.pdf.

———. 2021d. "PovcalNet." Text/HTML. PovCalNet. May 4, 2021. http://iresearch.worldbank.org/PovcalNet/povOnDemand.aspx.

———. 2021e. “Defying Predictions, Remittance Flows Remain Strong During COVID-19 Crisis [Press Release].” World Bank. May 12, 2021. https://www.worldbank.org/en/news/press-release/2021/05/12/defying-predictions-remittance-flows-remain-strong-during-covid-19-crisis.

World Data Lab. 2020. “World Poverty Clock.” June 30, 2020. https://worldpoverty.io.

World Food Programme. 2009. “Emergency Food Security Assessment Handbook Second Edition.” World Food Programme. https://documents.wfp.org/stellent/groups/public/documents/manual_guide_proced/wfp203246.pdf.

———. 2020a. “COVID-19 Will Double Number of People Facing Food Crises Unless Swift Action Is Taken | World Food Programme.” April 21, 2020. https://www.wfp.org/news/covid-19-will-double-number-people-facing-food-crises-unless-swift-action-taken.

———. 2020b. “World Food Program Market Monitor #48 - Basic Food Basket Cost Changes.” The Market Monitor. WFP World Food Programme. https://dataviz.vam.wfp.org/global-coverage-market-monitor-48-jul-2020?_ga=2.46600750.881030720.1620760701-1482088016.1620667102.

———. 2020c. “World Food Program Market Monitor #49 - Basic Food Basket Cost Changes.” 49. The Market Monitor. WFP World Food Programme. https://dataviz.vam.wfp.org/global-coverage-market-monitor-49-oct-2020?_ga=2.54016161.881030720.1620760701-1482088016.1620667102.

World Food Summit. 1996. “World Food Summit Rome Declaration on Food Security and Plan of Action.” Food and Agriculture Organization of the United Nations. http://www.fao.org/3/w3613e/w3613e00.htm.

WTO. 2021. “World Trade Primed for Strong but Uneven Recovery after COVID 19 Pandemic Shock.” 2021. https://www.wto.org/english/news_e/pres21_e/pr876_e.htm.

Yip, R., and T. W. Sharp. 1993. “Acute Malnutrition and High Childhood Mortality Related to Diarrhea. Lessons from the 1991 Kurdish Refugee Crisis.” *JAMA* 270 (5): 587–90.

Zanden, Emma H. van der, Peter H. Verburg, Catharina J. E. Schulp, and Pieter Johannes Verkerk. 2017. “Trade-Offs of European Agricultural Abandonment.” *Land Use Policy* 62 (March): 290–301. https://doi.org/10.1016/j.landusepol.2017.01.003.

Zeist, Willem-Jan van, Elke Stehfest, Jonathan C. Doelman, Hugo Valin, Katherine Calvin, Shinichiro Fujimori, Tomoko Hasegawa, et al. 2020. “Are Scenario Projections Overly Optimistic about Future Yield Progress?” *Global Environmental Change* 64 (September): 102120. https://doi.org/10.1016/j.gloenvcha.2020.102120.

Zhao, Chuang, Bing Liu, Shilong Piao, Xuhui Wang, David B. Lobell, Yao Huang, Mengtian Huang, et al. 2017. “Temperature Increase Reduces Global Yields of Major Crops in Four Independent Estimates.” *Proceedings of the National Academy of Sciences* 114 (35): 9326–31. https://doi.org/10.1073/pnas.1701762114.