Food inequality and climate change: compounding impacts on caloric undernutrition

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Abstract:

Anthropogenic climate change is expected to place additional pressure in the world's food systems which could lead to decreased food production (Hasegawa et al. 2014), decline in agricultural productivity (Ortiz-Bobea et al. 2021) and lower consumer well-being (Baldos, Hertel and Moore 2019; Gurgel, Reilly and Blanc 2021). Food security is also threatened by adverse climate impacts and past work have incorporated measures in caloric undernourishment which are generally driven by changes in average dietary energy intake (Baldos and Hertel 2014; Hasegawa et al. 2016; Janssens et al. 2020). This work builds on this literature by explicitly examining the compounding impacts of greater food inequality and climate-driven crop yield changes on food security. The latest mean ensemble of climate change crop yield impacts from the Coupled Model Intercomparison Project (CMIP6) (Jägermeyr et al. 2021) are combined with the projected changes in income inequality under different Shared Socioeconomic Pathways (SSPs) (Rao et al. 2019). Changes in income inequality are assumed to directly impact the distribution of caloric consumption in each region. Change in crop yields due to climate change and changes in income distribution under different scenarios are then used in a partial equilibrium model of agriculture to assess the impacts of these drivers in the underlying distribution of caloric consumption within food insecure countries. The results show that only a few food insecure regions face adverse crop yield impacts due to climate change and most countries are expected to face relatively mild if not positive crop yields in the future. However, increased income inequality in the future could completely offset these gains especially in countries with persistent inequality.

Introduction

Anthropogenic climate change is expected to place additional pressure in the world's food systems which could lead to decreased food production (Hasegawa et al. 2014), declining in agricultural productivity (Ortiz-Bobea et al. 2021) and lower consumer well-being (Baldos et al. 2019; Gurgel et al. 2021). Food security is also threatened by adverse climate impacts especially under extreme climate events (Hasegawa et al. 2021) and could threaten the gains that has been achieved in recent decades. Past work have incorporated measures in caloric undernourishment which are generally driven by changes in average dietary energy intake (Baldos and Hertel 2014; Hasegawa et al. 2016; Janssens et al. 2020). This work builds on this literature by explicitly examining the compounding impacts of greater food inequality and climate-driven crop yield changes on food security. Using growth and inequality elasticities from the poverty literature (Bourguignon 2003; Lopez and Serven 2006; Bergstrom 2020), this paper incorporates growth and inequalities elasticities for caloric distribution in order to track changes in undernutrition incidence due to changes in average per capita caloric consumption and to changes in the distribution of caloric consumption in each region. The latest mean ensemble of climate change crop yield impacts from the Coupled Model Intercomparison Project (CMIP6) (Jägermeyr et al. 2021) are combined with the projected changes in income inequality under different Shared Socioeconomic Pathways (SSPs) (Rao et al. 2019). Changes in income inequality are assumed to directly impact the distribution of caloric consumption in each region. Change in crop yields due to climate change and changes in income distribution under different scenarios are then used in a partial equilibrium model of agriculture to assess the impacts of these drivers in the underlying distribution of caloric consumption within food insecure countries.

Data and Methods

Climate change yield impacts and income inequality: Climate driven crop yield impacts are based on the ensemble of outputs from the Agricultural Model Intercomparison and Improvement Project which were produced using updated crop models and the latest climate outputs from the Coupled Model Intercomparison Project (CMIP6) (Jägermeyr et al. 2021). This data updates the harmonized crop model projections from Rosenzweig et al (2014) which is based on climate outputs from CMIP5. In this paper, average changes in crop yields over the

period 2017 to 2065 were calculated from the crop model ensemble mean for three main crops (maize, wheat and rice) and for five climate model outputs under the high emission scenario (Representative Concentration Pathway 8.5). CO_2 fertilization is also considered in these projections which could boost yields for these crops. Crop specific yield changes where then aggregated using the value of crop production from FAOSTAT (FAO 2023) (see Table 1). These outputs can be accessed using the latest AgMIP tool (Jägermeyr 2022). Changes in food distribution in this paper were based on the changes in income Gini coefficients across different shared socio economic pathways which were calculated by Rao et al (Rao et al. 2019). The authors calculate the changes in income distribution using an econometric model which estimates Gini coefficients as a function of total factor productivity (TFP), education, social policies, and other variables. The authors calculated these estimates for five Shared Socioeconomic Pathways (SSP). In this paper, Gini coefficient estimates for SSP1 (Sustainability), SSP2 (Middle of Road) and SSP3 (Regional Rivalry) were used. High improvements in income inequality are projected under SSP1 (see Table 1). Under this scenario, there is lower inequality across developing and developed countries as well as within countries. Gains in education as well as growth and convergence in TFP are also assumed. SSP3 represents the opposite of SSP1 and assumes that income inequality is expected to increase across countries. It also assumes lack of gains in productivity growth and convergence as well as lower spending in education. Finally, SSP2 is in between SSP1 and SSP3 and is a scenario that extrapolates historical trends and assumes that current progress made in improving income inequality in some regions would continue to the future.

*Model***:** In this paper, the results were generated using the SIMPLE modeling framework (Simplified International Model of agricultural Prices, Land use, and the Environment) a global-partial equilibrium model of agriculture (Baldos et al. 2020). It focuses on the production and consumption of three aggregate food commodities (crops, livestock and processed foods). Production decisions are modeled following the Constant Elasticity of Substitution (CES) production function (McFadden 1963) allowing producers respond to changes in output and input prices. Under this framework, input substitution is determined by the changes in relative input prices and the elasticities of input substitution. Regional livestock and processed foods sectors use aggregate crop and non-crop inputs. Consumption of food commodities is estimated at the regional level and is driven by exogenous growth in population, income, feedstock demand

from biofuel mandates. Consumption is also a function of endogenous price changes. Changes in dietary patterns are captured by linking per capita income levels to price and income demand elasticities. Prices are determined by the market clearing condition where supply is equal to demand at the regional and global levels. The market clearing for livestock and processed foods occur at the regional level. For crops, consumers and producers tap both domestic and global markets and they respond to the relative prices of locally produced crops and crops purchased in the world market. This follows the Armington trade model (1969; Anderson 1979) by allowing imperfect substitution between products in the local and global markets but without fully incorporating bilateral trade flows across regions. In this paper, the database for the year 2017 is used which covers 129 regions using crop production data from FAOSTAT (FAO 2023) and economic data from the GTAP v.11 database (Aguilar et al, 2022). These include input cost shares for livestock and processed food commodities, crop utilization shares, and producer revenue as well as consumer expenditure shares for crops in the domestic and global markets. Input cost shares for crop production are also used. The regional crop allocation shares for the biofuel sector are taken from GTAP-BIO database (Taheripour, Zhao and Tyner 2017).

The nutritional outcomes from SIMPLE are based on caloric consumption and undernutrition data from FAOSTAT (FAO 2023). In the model, distribution of caloric consumption is imposed for each country which permits the calculation of caloric undernutrition incidence which reports the fraction of population whose daily dietary energy intake is below the minimum requirement. The undernutrition count is then derived by multiplying the undernutrition incidence with population. Food caloric content also evolve using estimates from linear regressions with per capita incomes and food caloric content (Baldos and Hertel 2014). Finally, shifts in average per capita dietary changes are then linked to the changes in undernutrition incidence and count using growth and inequality elasticities. Widely used in the poverty literature, growth and inequality elasticities measure the percent change in the poverty index given a one percent change in average per capita income and given a one percent change in the standard deviation of log of per capita income (Bourguignon 2003; Lopez and Serven 2006; Bergstrom 2020). To apply these concepts in the case of dietary energy, we assume that the distribution of per capita dietary energy consumption is lognormal. This is consistent with the traditional assumption used by FAO regarding the distribution of dietary energy intake within a

country (Neiken 2003). The following equations are used to calculate the growth (ε_{UG}) and inequality (ε_{UI}) elasticities for the undernutrition index:

$$\varepsilon_{UG} = -\frac{1}{\sigma}\frac{\tau\left(\frac{\ln(w/y)}{\sigma}+\frac{\sigma}{2}\right)}{\pi\left(\frac{\ln(w/y)}{\sigma}+\frac{\sigma}{2}\right)} \quad (1)$$

$$\varepsilon_{UI} = -\frac{1}{\sigma}\frac{\tau\left(\frac{\ln(w/y)}{\sigma}+\frac{\sigma}{2}\right)\left(\frac{\sigma}{2}-\frac{\ln(w/y)}{\sigma}\right)}{\pi\left(\frac{\ln(w/y)}{\sigma}+\frac{\sigma}{2}\right)} \quad (2)$$

In these equations, w is the minimum daily energy requirement (MDER), y is the average per capita dietary energy intake, and σ is the standard deviation of the log of caloric distribution. The operators: τ and π denote the standard normal probability density and cumulative distribution functions, respectively.

4. Results

This section reports the key results of the simulations under four scenarios: (S0) Climate change yield shocks only, (S1) S1 + SSP1 income distribution shocks, (S2) S1 + SSP2 income distribution shocks, and (S3) S1 + SSP3 income distribution shocks. Note that the results focus only on food insecure countries with undernutrition count of more than a million persons and undernutrition index above 5% in year 2017.

Changes in average caloric consumption: Figure 1 shows the changes in crop yields (blue bars) due to climate change and the changes in average caloric consumption (orange bars) for food insecure countries. Recent estimates of climate change driven yield impacts indicate that the majority of food insecure countries are expected to face lower crop yields in the future. In Sub Saharan Africa, several countries in this region face declining caloric consumption due to notable adverse climate change impacts including Benin, South Africa, Cameroon and Côte d'Ivoire. In South Asia, Pakistan face reduction in caloric consumption due to large negative impacts of climate change on crop yields. Other food insecure regions which face milder losses in crop

yields face smaller losses in average caloric consumption. Of course, there are many regions which face flat or even positive yield changes due to climate change. In Kenya, Niger, Ethiopia and Mozambique, farmers face yield improvements due to climate change which leads to increases in average caloric consumption. Other countries which face improvements in both crop yields and average caloric consumption include Afghanistan in South Asia, Peru, Ecuador and Bolivia in Latin America & Caribbean and Tajikistan in Europe & Central Asia.

Changes in undernutrition incidence: Figure 2 reports the changes in the prevalence of caloric undernutrition across all four scenarios. Under S0 which focuses only on climate change impacts (grey bars), lower crop yields and average caloric consumption results in increasing incidence of caloric undernutrition. This is observed in Ghana, Benin, South Africa, Cameroon and Côte d'Ivoire in Sub Saharan Africa and Pakistan in South Asia. The largest increase in undernutrition incidence in S0 is observed in Central African Republic which is due to the high proportion of population which face caloric undernourishment (around 47% in Y2017). Countries such as Kenya, Niger, Ethiopia and Mozambique which face positive yield impacts due to climate change and gains in average caloric consumption show reduction in caloric undernutrition incidence. Majority of the food insecure countries are expected to face lower inequality in food availability under S1 which has the lowest food inequality across scenarios. These improvements are more than sufficient to offset the adverse impacts of climate change in food insecure countries. For example, Benin, South Africa, Cameroon and Côte d'Ivoire now face reduction in undernutrition incidence compared to increases under S0. This is also observed in Pakistan. Under S2, most of the food insecure countries still expected reduction in inequality apart from India. The persistence of inequality in India under S2 is more than enough to offset the mild impact of climate change on undernutrition incidence in the country. The lack of improvement in Gini coefficient in India is mainly due to the low level of investments in public spending in education (Rao et al. 2019). Tajikistan and Peru also experienced greater food inequality in S2 which is more than enough to offset the positive gains in crop yields due to climate change. Among scenarios, greater food inequality is expected under S3 for all food insecure countries. For countries which already expect adverse climate change impacts on yields, growing inequality makes food insecurity more severe. Countries which experience greater prevalence of caloric undernutrition due to the compounded effects of adverse climate change impacts and growing inequality includes Benin, South Africa, Cameroon and Côte d'Ivoire in Sub Saharan Africa as

well as Pakistan in South Asia. Greater inequality increased food insecurity more than climate change in India, Peru, Ecuador, Tajikistan and the Philippines.

Changes in undernutrition count: Figure 3 reports the changes in the undernutrition count across all four scenarios. In scenario S0, strong reductions in undernutrition count which are driven by positive impacts of climate change in crop yields resulted in 12.8 million persons lifted out of caloric undernutrition in food insecure regions. These are observed in India, Bangladesh and Afghanistan in South Asia, Ethiopia, Kenya, Congo Dem. Rep., Mozambique and Niger in Sub Saharan Africa as well as Romania in Europe & Central Asia. However, undernutrition count increased in Indonesia, Nigeria and Pakistan due to the negative impact of climate change on crop yields in these countries. Greater food equality lifted around 176.8 million persons out of hunger under S1. More than half of these persons reside in India, Romania, Bangladesh, Ethiopia, Indonesia, Pakistan and Congo, Dem. Rep., Nigeria and the Philippines. Under S2, only 1.4 million persons escape caloric undernutrition in food insecure countries. Most countries show reduction in undernourishment count and most of these persons live in Romania, Ethiopia, Bangladesh, Indonesia, Pakistan, Congo, Dem. Rep. and Thailand. However, these gains are completely offset by the increased food insecurity due to inequality in India which results in additional 96.2 million persons whose daily average caloric intake are below the minimum dietary requirement. With greater inequality, more persons in food insecure countries are pushed to caloric hunger. In total, around 144.9 million persons face caloric undernutrition in these regions with most of them residing in Philippines, Nigeria, Indonesia, Romania, Pakistan and India.

5. Summary

This paper examines the potential impact of climate change on food security using the latest crop yield impact estimates as input to a global partial equilibrium model of agriculture. It also considers the compounding effects of greater food inequality by using projections of income inequalities for 3 different Shared Socio-Economic Pathways. The results show that only a few food insecure regions face adverse crop yield impacts due to climate change and most countries are expected to face relatively mild if not positive crop yields in the future. This results in slight improvements in the average caloric consumption, caloric undernutrition incidence and count.

With greater food equality under S1 (“Sustainability”), most food insecure regions face further reduction in undernutrition incidence and count. In most countries, these gains are more than enough to offset the adverse impacts of climate change on caloric undernutrition incidence and count. Under scenario (“Middle of Road”) most regions still see improvements in food equality which leads to overall gains in food security outcomes. However, increased inequality expected in India is large enough to offset the gains observed in other food insecure regions. Finally, increased inequality under S3 (“Regional Rivalry”) results in more persons being pushed into chronic caloric hunger especially in regions which already face adverse crop yield impacts from climate change. The results presented in this paper are preliminary. Future work will focus on developing a baseline for future projections from 2017 to 2065 and will including climate change impacts on labor due to heat stress.

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Figures and Tables

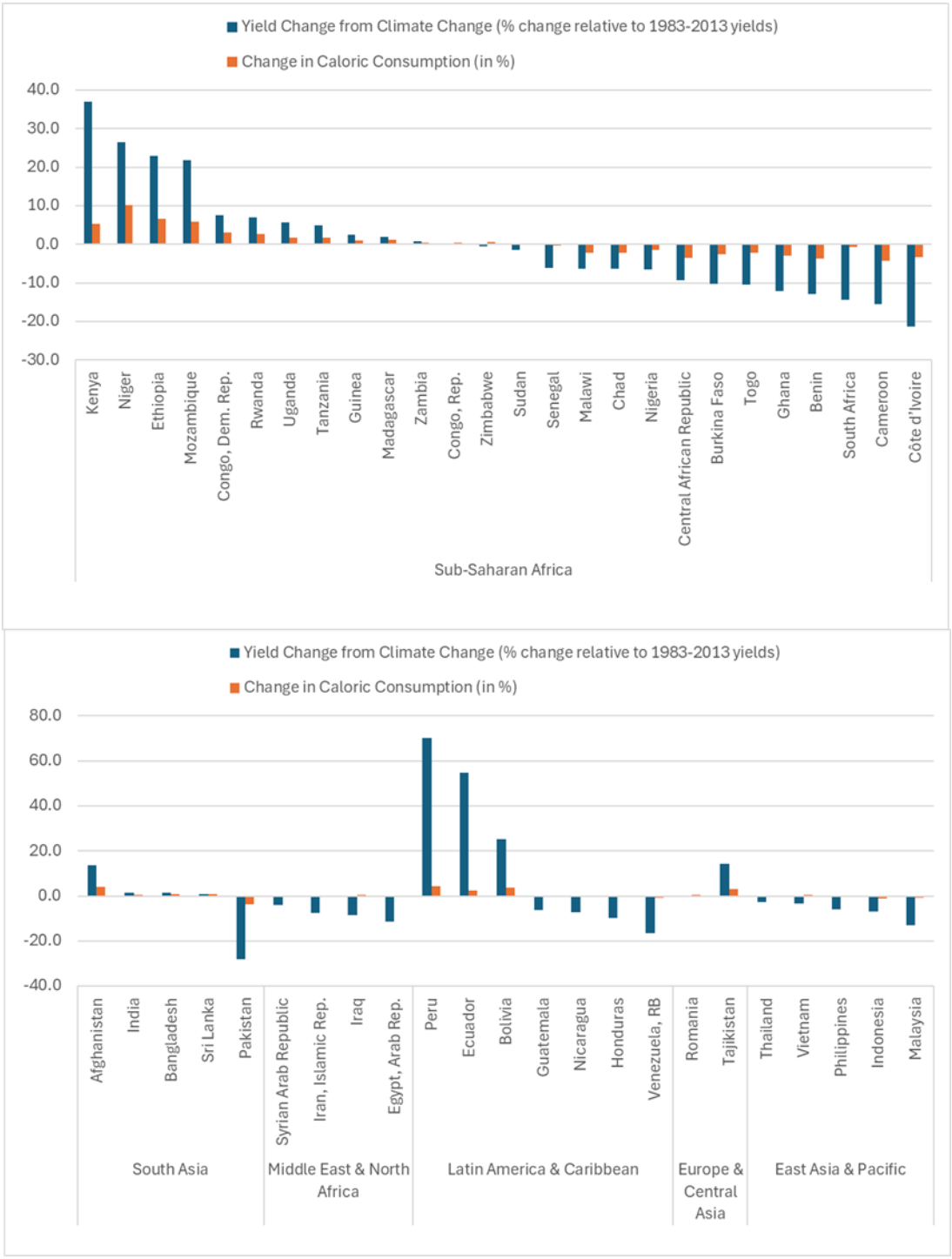


Figure 1. Changes in average crop yields and average caloric consumption in food insecure regions from 2017 to 2065.

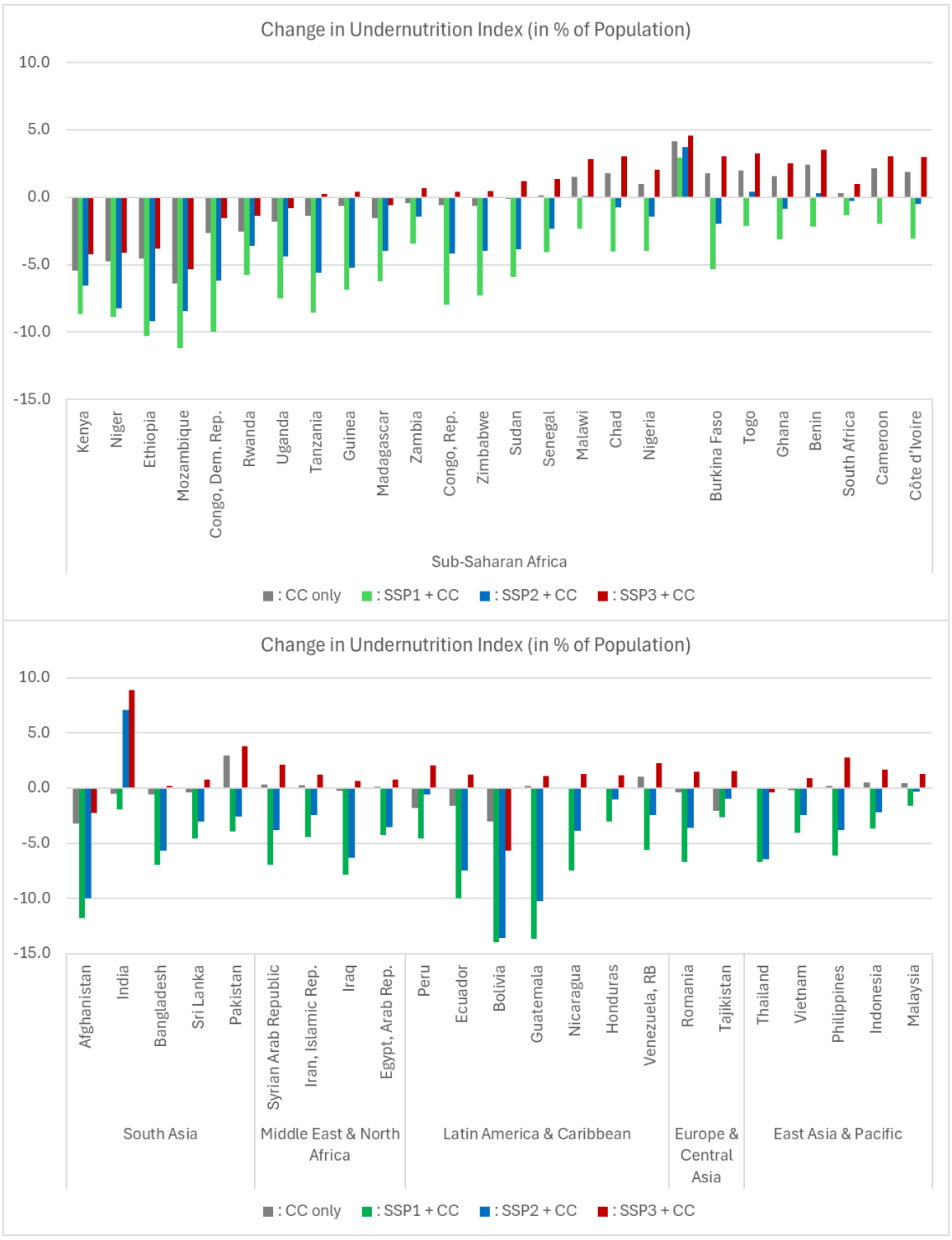


Figure 2. Changes in undernutrition incidence in food insecure regions across all scenarios from 2017 to 2065.

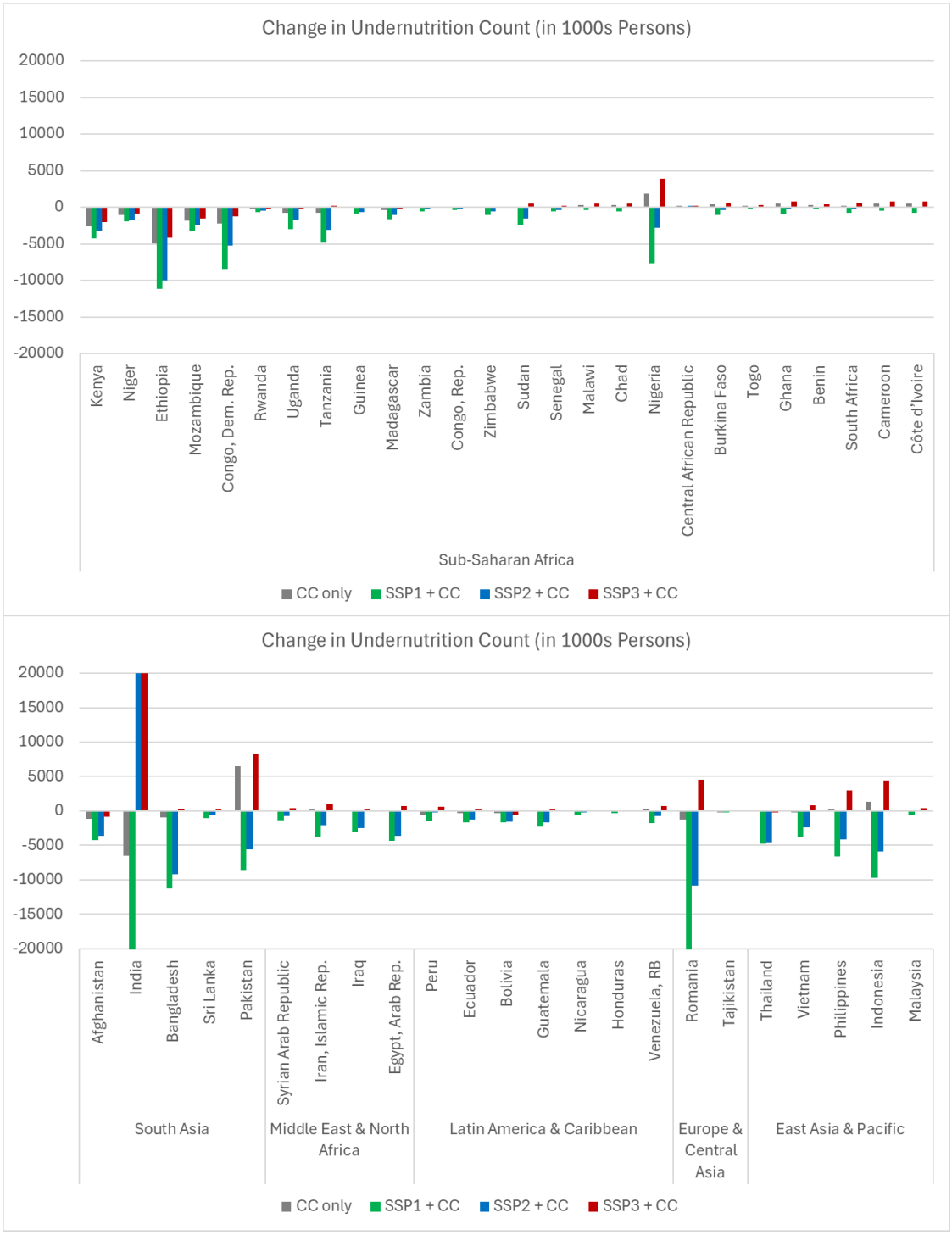


Figure 3. Changes in undernutrition count in food insecure regions across all scenarios from 2017 to 2065.

Table 1. Changes in average crop yields and income distribution in food insecure regions from 2017 to 2065.

Region	Country	Yield Change from Climate Change (% change relative to 1983-2013 yields)	% Change in Standard Distribution of Income Distribution		
			SSP1: Sustainability	SSP2: Middle of the road	SSP3: Regional rivalry
Sub-Saharan Africa	Kenya	36.9	-10.2	-3.6	3.9
	Niger	26.5	-21.9	-17.5	2.6
	Ethiopia	23.0	-20.9	-16.7	2.5
	Mozambique	21.8	-14.7	-6.6	3.7
	Congo, Dem. Rep.	7.5	-20.2	-10.3	3.5
	Rwanda	7.0	-9.7	-3.4	3.7
	Uganda	5.8	-17.7	-8.5	3.7
	Tanzania	4.9	-20.1	-12.0	5.0
	Guinea	2.4	-20.6	-15.0	3.4
	Madagascar	2.0	-19.8	-10.9	4.7
	Zambia	0.8	-9.0	-3.1	3.5
	Congo, Rep.	0.0	-22.2	-11.5	3.6
	Zimbabwe	-0.5	-21.5	-11.5	4.2
	Sudan	-1.5	-21.0	-13.3	4.7
	Senegal	-6.1	-19.4	-10.9	5.0
	Malawi	-6.4	-11.5	-4.3	4.0
	Chad	-6.4	-16.3	-7.5	3.8
	Nigeria	-6.6	-17.7	-8.5	3.7
	Central African Republic	-9.3	-8.9	-3.1	3.4
	Burkina Faso	-10.3	-21.8	-11.5	3.9
	Togo	-10.5	-12.1	-4.7	4.0
	Ghana	-12.0	-18.5	-9.1	3.6
	Benin	-12.9	-15.8	-7.2	3.8
	South Africa	-14.3	-8.0	-2.8	3.1
	Cameroon	-15.4	-18.3	-8.9	3.7
	Côte d'Ivoire	-21.3	-16.9	-7.9	3.8
South Asia	Afghanistan	13.8	-24.3	-19.4	2.9
	India	1.5	-4.9	27.3	34.3
	Bangladesh	1.4	-21.6	-17.2	2.6
	Sri Lanka	0.9	-20.1	-12.0	5.0
	Pakistan	-28.1	-23.1	-18.4	2.7
Middle East & North Africa	Syrian Arab Republic	-4.1	-21.3	-12.1	5.6
	Iran, Islamic Rep.	-7.5	-21.8	-11.5	4.0
	Iraq	-8.4	-22.2	-17.7	2.6
	Egypt, Arab Rep.	-11.3	-22.3	-17.8	2.6
Latin America & Caribbean	Peru	70.2	-17.7	6.3	18.7
	Ecuador	54.8	-41.5	-24.5	10.8
	Bolivia	25.2	-54.7	-47.7	-9.5
	Guatemala	-6.1	-51.7	-33.8	2.9
	Nicaragua	-7.3	-21.8	-11.5	4.0
	Honduras	-9.9	-9.7	-3.4	3.7
	Venezuela, RB	-16.6	-20.1	-11.0	4.4
Europe & Central Asia	Romania	0.0	-18.2	-9.4	6.0
	Tajikistan	14.2	-2.0	4.0	12.9
East Asia & Pacific	Thailand	-2.6	-50.0	-41.9	-1.3
	Vietnam	-3.3	-19.9	-10.9	4.7
	Philippines	-5.9	-42.9	-20.2	10.9
	Indonesia	-7.0	-21.2	-12.8	5.1
	Malaysia	-13.1	-10.7	-3.7	4.1

Sources: Changes in crop yields are based from Jägermeyr (2021) and changes in standard deviations are calculated from the estimates from Rao et al. (2019)