Who is Most Vulnerable to Climate Change Induced Yield Changes? A Dynamic Long Run Household Analysis in Lower Income Countries

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Abstract

Climate change impacts on agricultural production will shape the challenges of reaching food security and reducing poverty across households in the future. Existing literature lacks analysis of these impacts on different household groups under consideration of changing socio-economic developments. Here, we analyze how crop yield shifts induced by climate change will affect different household types in three low and low middle-income countries, namely Vietnam, Ethiopia and Bolivia. The long-run analysis is based on a recursive-dynamic Computable General Equilibrium model. We first construct a baseline scenario projecting global socio-economic developments up to 2050. From there, we implement business-as-usual climate change shocks on crop yields. In the baseline, all households benefit from welfare increases over time. Adding climate change induced yield changes reveals impacts different in size and direction depending on the level of the households' income and on the share of income generated in agriculture. We find that the composition of the factor income is of large importance for the vulnerability of households to climate change, as, the loss for non-agricultural households is highest in absolute terms. The complementary comparative static analysis shows smaller absolute and relative effects for most households as the differentiated factor income growth over time is not considered, which makes household types more or less vulnerable. A sensitivity analysis varying the severity of climate change impacts on yields confirms that more negative yield shifts exacerbate the situation of the most vulnerable households. Furthermore, it underlines that yield shocks on staple crops are of major importance for the welfare effect. Our findings reveal the need for differentiated interventions to mitigate consequences especially for the most vulnerable households.

1   Introduction

Vulnerability to climate change is one of the main challenges faced by humankind in the 21st century (Godfray et al., 2010). Many low-income countries (LIC) are expected to face high vulnerability with large population shares in high risk areas, poorly developed health infrastructure and weak adaptation

capacities (Haines et al., 2006). Within countries, climate change vulnerability differs across population strata, for instance, depending on income sources and levels (e.g. Winsemius et al. (2015)), and between rural and urban regions (e.g. Pandey et al. (2015), Ahmed et al. (2009)). Farmers are often identified as especially vulnerable to direct impacts (Deressa et al., 2008) due to reduced average crop yields or more frequent crop failures. The reduced production can, however, increase prices to their benefit, as seen during the food price crises around 2007 (Cohen and Garrett, 2010). Higher crop prices harm households that are poor net buyers of food, which often are rural non-agricultural households (Aksoy and Isik-Dikmelik, 2008). As net sellers and net buyers of food face different repercussions, distributional effects of agricultural climate change impacts need to be considered.

Some studies have addressed this by introducing household types in climate change assessments. Hertel et al. (2010) studied effects of climate change driven productivity shifts of six crops on seven household groups in fifteen developing countries. A similar study by Skjeflo (2013) for Malawi, with a focus on maize, differentiated eight household types. Both papers assess impacts of likely future crop yield changes in consequence of decades of climate change in the economic setting of today. Macro-economic and population dynamics happen in parallel to climate change and affect income levels, earning and consumption patterns, which determine vulnerability to changes in crop productivity.

Thus, a holistic forward-looking perspective in climate change assessments is needed as provided by the five Shared Socio-Economic Pathways (SSPs), developed for integrated long-term analyses of climate change mitigation and adaptation (Riahi et al., 2017). Each SSP describes a different qualitative narrative about the global socioeconomic developments with SSP2 depicting a "Middle of the Road" development. The narratives were the basis to develop long-term macro-economic projections of population dynamics and income growth (Dellink et al., 2017; KC and Lutz, 2017). These projections in combination with the narratives have been enriched with further detail for assessments in terms of e.g. climate change (Leimbach and Giannousakis, 2019) or land use change (Popp et al., 2017), or refined with sub-national detail (Dong et al., 2018; Britz et al., 2019). Studies based on the SSPs draw on various model types including dynamic computable general equilibrium (CGE) models as an established method for long-run economic analysis with sectoral detail (Fujimori et al., 2017; Doelman et al., 2018; Britz et al., 2019).

Direct impacts of climate change differ across crops, and their consequences for food availability depend on factors such as global market integration and regional diets. Existing work based on the SSPs does not combine macro-economic mechanisms including agri-food detail with household differentiation. A study from Hallegatte and Rozenberg (2017) assessed household level effects of climate change using a microsimulation approach under SSP4 and SSP5. However, in this study neither trade, nor investment changes over time are considered. We address this gap by carrying out an ex ante assessment of climate change induced yield shifts based on dynamic global CGE modeling. To this end,

we incorporate detail for nine different household types, grouped by income per capita and share of agricultural income, for Vietnam, Ethiopia, and Bolivia as low- and lower-middle-income countries (LMICs). With this framework, we can model crucial developments over time such as income dependent household demand curves and endogenous national saving rates, which depend on demographics and income. The baseline draws on projections of population, educational levels and GDP for SPP2 until 2050. It captures increasing demographic pressures on cropland resources and the changing importance of the agri-food sector in the overall economy as GDP rises, which forms the impacts from crop yield changes. In order to isolate the effect of climate change on different household types, we compare our baseline (*no_CC*) without explicit climate change assumptions on agricultural production to a scenario in which we consider climate change induced yield shifts for eight crop aggregates globally (*bau_CC*). In addition, we run a comparative static analysis to show the added value of the dynamic analysis i.e. revealing the relevant driving dynamics explicitly, which are ignored in a comparative static setting. The uncertainty of the yield shocks is assessed as part of a sensitivity analysis varying crop yield changes in the recursive dynamic analysis by considering projections under different future atmospheric CO_2 concentrations.

Detailed information about the approach is provided in Chapter 2, which includes the model description, household representation, yield shift assumptions and the scenario design with the indicator descriptions. Chapter 3 then presents the results by describing country specific effects both economy wide and at household level. It further includes the results of the comparative static analysis and the sensitivity analysis. Finally, relevant limitations and uncertainties are discussed in Chapter 4 and a conclusion is drawn in Chapter 5.

2   Methods

2.1   *Model description*

We employ a recursive dynamic global CGE model implemented in the flexible and modular modeling framework CGEBox (Britz and van der Mensbrugghe, 2018), which takes as its core the standard GTAP model (Hertel and Tsigas, 1997) in its current version 7 (Van der Mensbrugghe, 2018). It depicts constant-returns-to-scale industries without market power, revenue maximizing factor suppliers and utility maximizing consumers. Moreover, it comprises various exhausting conditions and macro-economic balances such as investments equal savings, and international capital flows offsetting the balance of trade. Bi-lateral trade is represented in two stages based on the 'Armington assumption' (Armington, 1969), which differentiates products by origin, considering transport margins, export taxes (or subsidies) and import tariffs. Various further subsidies and taxes in input and output markets are considered in prices for producers, factor supplier and consumers.

We extend this core by the recursive-dynamic G-RDEM model (Britz and Roson, 2019) combined with elements of the GTAP-E (McDougall and Golub, 2009), GTAP-AGR (Keeney and Hertel, 2005) and GTAP-AEZ (Lee, 2005) modules, to consider detail for energy, agriculture and land use. G-RDEM is designed for the construction of internally consistent and detailed scenarios of long-run economic development (Britz and Roson, 2019). Besides the capital accumulation component typically applied in recursive dynamic CGEs, G-RDEM adds five features, capturing key adjustment processes in the long run: (1) an econometrically estimated implicitly directly additive demand system (AIDADS) with non-linear Engel curves to depict income dependent variations in household consumption patterns, (2) sectoral differentiated total factor productivity growth depending on GDP growth, (3) endogenous national aggregate saving rates driven by demographic and income dynamics, (4) time-varying and income dependent industrial input-output parameters, and (5) debt accumulation generated from foreign savings and trade imbalances (Britz and Roson, 2019).

G-RDEM uses exogenous projections of real GDP and population by age and educational level provided by the SSP database (Riahi et al., 2017) during baseline construction. At each period t, the model is solved for a simultaneous equilibrium in all commodity and factor markets globally. Endogenous aggregate factor productivity adjusts in accordance with the exogenous GDP changes and drives the sector-specific productivity shifters. Before each iteration, net investments define the capital stocks at t+1, whereas population and labor stocks, saving rates and input-output coefficients are exogenously updated. In our counterfactual scenario runs we include climate change assumptions. Here productivity shifters turn exogenous and are taken from the baseline run, while GDP now reacts endogenously.

We add some features of the GTAP-E model, which provides detail in depicting the demand for energy carriers by industries and final households to better capture technical substitution. Similarly, the GTAP-AGR model depicts substitution among feedstuffs in livestock production, as well as specific groups of food products to capture cross-price effects in the top-level final demand for food. The GTAP-AEZ model disaggregates land into specific uses across different agro-ecological zones (AEZs). There are 18 AEZs in total, which result from distinguishing tropical, temperate, and boreal zones further differentiated by the length of growing seasons. We extend the GTAP-AEZ formulation by considering land supply from natural vegetation. As land expansion to forestry and agriculture mostly serves to increase cropland, we use the remaining available cropland buffers as an estimate for the maximal area, which can be converted from natural vegetation. The land supply elasticities are adjusted to match forecasts by FAO (2018) from which we also take yield trends.

We draw on version 9 of the GTAP database (Aguiar et al., 2016), which provides a snapshot of the global economy for 2011. We keep the full differentiation of 57 sectors, which comprise, inter alia, 12 agricultural, 6 energy and 3 transport sectors. In the result section, the results of the detailed

agricultural sectors are often aggregated into a 'grains and crops' and a 'livestock and meat' sector. In addition, the processed food sector is studied, which is also contained when referred to the overall 'agri-food sector' in the following. All monetary values are presented in USD 2011 in line with the model database. We aggregate the 140 countries or country blocks included in GTAP 9 into 15 regions. This includes an LICs (Ethiopia) and two LMICs (Bolivia and Vietnam) considered with household details as well as China and the USA, and 10 country aggregates (see in Table A.1 for detail). We opted for the three case study countries as they are located in different regions around the world and thus face different conditions, both climatic and economic. In addition, the choice reflects data availability, i.e. we need LICs or LMICs represented as a single region in GTAP 9 for which a FAO household survey is available, see next section.

2.2   *Household representation*

As the standard GTAP model, G-RDEM normally considers only one representative consumer in each country or region. Here, we instead exploit information from a set of household surveys (FAO, 2017), which provide, inter alia, information on income composition for selected LICs and LMICs, with detail and focus on farming households. The Ethiopian survey is called Ethiopian Rural Socioeconomic Survey and was constructed for rural areas and small towns. The surveys for Bolivia and Vietnam are representative for the whole population (FAO, 2017). Besides data on household size and their weight in the population, we include information on the source of income differentiating (self-) employment in ten different sectors. Furthermore, we take government or intra-household transfers, remittances and other income sources into account. In the underlying survey data both monetary and in kind (e.g. own produced food) receipts are used to depict income (ILO, 2003). Thus, also products that do not enter the market are valued as income.

We group the households in three quantiles by income per capita: poor (I30: 30% quantile), middle (I70: 30% up to 70%) and rich (I100: rest), considering their weights in the total population. Moreover, we use the share of their income generated in agriculture to capture the distinction between net sellers and net buyers of food. Again, we use the same percentage allocation, resulting in three quantiles encompassing the households with the lowest 30% (A30), the middle (A70: 30% up to 70%) and the highest 30% of the shares of agricultural in total income (A100). The combination of these quantiles results in nine household types. Table 1 reports the population shares represented by household type.

Table 1: Share of each household type on population (%)

	I30_A30	I30_A70	I30_A100	I70_A30	I70_A70	I70_A100	I100_A30	I100_A70	I100_A100
VNM	9	12.5	17.1	8.9	15.2	8.8	13.5	9.8	5.1
ETH	6.5	8.7	12.3	5.1	20.7	15.9	6	13.8	10.9
BOL	11.4	1.6	15.2	27.3	3.2	8.9	27.4	2.5	2.4

Remark: VNM = Vietnam, ETH = Ethiopia, BOL = Bolivia, Household type (e.g. I30_A30) are named according to the total income per capita quantile (e.g. 30% quantile of total income: I30) and share of agricultural income (30% quantile of agricultural income: A30) that they represent. *Source: Model simulation based on data from FAO (2017)*

We employ the myGTAP module in CGEBox to introduce income and consumption related data from the household surveys in the social accounting matrix ensuring consistency with the aggregated GTAP data. Each household is assumed to own property rights to primary factors (skilled and unskilled labor, land, capital, natural resources), which are allocated to the different sectors subject to the revenues maximization objective based on a Constant Elasticity of Transformation function.

For the integration of multiple household types into the accounting framework of the CGE model, the single representative consumer is disaggregated (with fixed weights obtained by survey data) in each country. Household specific saving rates are updated based on a regression analysis underlying the saving rate dynamics in G-RDEM. Vectors of income from different sources are disaggregated based on income shares provided by the surveys. On the consumption side, the vector of final consumption is split down to the household types by using marginal budget share from the AIDADS demand system, to determine fitting baskets as the surveys do not report household consumption patterns. A balancing step ensures that each household exhausts its spending on final consumption. Adding up over the households exhausts the reported total economy-wide household consumption of each product. From there, the parameters of the AIDADS demand system are determined for each household.

Population development projections are available at country level only, so that we update all household types proportionally to total population. Capital income is assigned to the households on the basis of fixed ownership shares, which implies that household specific capital stocks vary proportionally. There is no migration from one household category to another and the proportion of skilled versus unskilled workers varies with the same rates across all households, reflecting projections of education levels.

2.3 *Climate change representation*

We consider yield shifts from FAO (2018) provided for three scenarios, namely a "business as usual scenario" (BAU), a "stratified society scenario" (SSS), and a "towards sustainability scenario" (TSS). For each scenario, country specific technology and climate change yield shifters are developed for 36
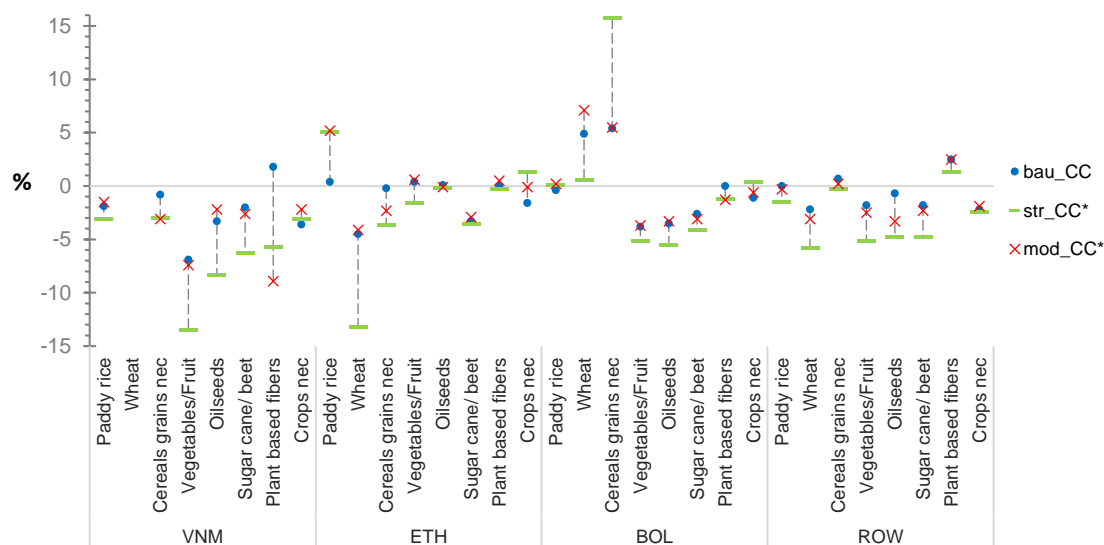
different crops. The climate change impacts are associated with the so-called Representative Concentration Pathways: RCP 6.0 (BAU), RCP 8.5 (SSS) and RCP 4.5 (TSS), while the socio-economic and technology developments draw on the SSPs (BAU: SSP2, TSS: SPP1, SSS: SPP4). Yield projections from FAO (2018) are aggregated to the available crops in the GTAP database and to model regions.

2.4   *Scenario design*

To assess impacts of yield shifts, we first construct a baseline scenario upon 2050 using GDP, population and workforce assumptions from SSP2 from the IIASA database. We choose SSP2 for the assessment as it consists of narratives that build on historical development patterns for future trends and thus represent on average a medium challenges scenario. Our baseline includes yield changes reflecting evolving technology from the BAU scenario in FAO (2018) which matches SSP2. However, as the original SSP scenario narratives do not consider climate change feedbacks, yield shifts induced by climate change are not incorporated in our baseline scenario (Riahi et al., 2017).

We then compare the baseline to a counterfactual scenario (bau_CC), which reflects impacts of climate change on yields at unchanged technological change both taken from the BAU scenario of FAO (2018). The resulting shocks are depicted in Figure 1, with rest of the world (ROW) representing the unweighted average of the shocks implemented in the regions which are not in the focus of the analysis. In the bau_CC scenario, the workforce and population data used in the baseline are adopted, while GDP adjusts endogenously.

Figure 1: Percentage change in yields induced by climate change, implemented in the shock scenarios until 2050.

Remark: bau_CC = business as usual Climate change scenario, str_CC = strong climate change scenario, mod_CC = moderate climate change scenario, * = sensitivity analysis scenarios, VNM = Vietnam, ETH = Ethiopia, BOL = Bolivia, ROW = unweighted average of the rest of the world, nec = not elsewhere classified. *Source: Based on data from FAO (2018)*

We provide new insights as to how climate change induced yield shifts affect the equilibria in primary factor and product markets, and prices, considering bi-lateral trade to ultimately assess income effects on specific household types. To this end, we make a detailed comparison of the bau_CC scenario to the baseline. We use the equivalent variation (EV) as a welfare indicator for the household types, which can be interpreted as the income change needed to reach the new welfare level at old prices (Bockstael and McConnell, 1980). The EV is expressed in monetary units, allowing for an intuitive interpretation. Furthermore, as an ordinal welfare indicator, the EV enables to rank counterfactual prices and quantities to a given base price as a benchmark - as it is applied in our simulation (McKenzie, 1988). Additionally, we present the EV change induced by the yield shift relative to the income of each household type in the baseline, deflated with the GDP price index, to illustrate the importance of the respective change for a household's welfare loss.

Complementary to the dynamic analysis, we perform a comparative static analysis to determine the additional contribution of considering long-run global economic changes, and identify decisive developments that would remain hidden in the latter. Here, we implement the same yield shock as in the dynamic analysis, while we do not consider i.a. GDP development or population growth over time. Finally, as part of a sensitivity analysis, we vary the severity of climate change impacts on crop yields in our two additional scenarios str_CC (based on the rather strong SSS climate change effects) and mod_CC (based on the moderate TSS climate change effects), which are constructed as the bau_CC scenario. For these two scenarios, the technology shifter is also taken from the BAU scenario as

technological progress follows the SSP2 assumptions aiming to disentangle the consequences of climate change severity ceteris paribus.

3   Results

3.1   *Baseline development*

Figure 2: (A) Change of population and GDP relative to 2011 and (B) GDP per capita development until 2050 in the study countries

Source: Based on data from Riahi et al. (2017)

The SSP2 projections imply that until 2050 global population grows by 32% and real GDP by 186%, resulting in a considerable GDP per capita growth (117%) compared to 2011. For the study countries, even higher changes in real GDP are projected approximately by factor six in Vietnam and Bolivia and by factor eleven in Ethiopia ('solid lines' Figure 2 A). Combined with population increases of 18% in Vietnam, of 87% in Ethiopia and of 42% in Bolivia until 2050 ('dashed line' Figure 2 A), this implies strong GDP per capita increases (Figure 2 B). These exogenous trends require considerable endogenous adjustments such as massive capital accumulation and sizable improvements in factor productivity over the baseline, and imply strong structural change in the economies. This relates, for instance, to the composition of consumption and production, primary factor endowments and their relations, and prices of input and outputs.

Economy wide effects

The combination of a growing world population and increases in per capita purchasing power let global economic output increase by 217% from 2011 to 2050. Compared to the global average economic output increase, output growth for grains and crops (59%) and for livestock and meat products (120%) is more modest, reflecting mostly lower income elasticities. Likewise, the processed food sector increases by 74% only. Thus, the share of agricultural in total output decreases from 4% to 2%.

Similarly, the share of processed food halves globally to 2%. An even stronger trend of falling agricultural importance is observed in Vietnam (by -8 percent points), Ethiopia (by -17 percent points) and Bolivia (by -9 percent points), with the share remaining largest in Ethiopia. Likewise, the importance of the processed food sector decreases in all three countries, by at most 5 percent points. For the three countries in focus, output developments differ substantially from global averages, as summarized in Table 2. While growth rates differ, output of all crops is projected to increase in all three countries until 2050.

Table 2: Share of each household type on total number of households (%)

	Total output	Grains and crops	Livestock and meat	Processed food
Global	217	59	120	74
VNM	608	43	491	151
ETH	1293	198	1334	349
BOL	549	47	217	120

Remark: VNM = Vietnam, ETH = Ethiopia, BOL = Bolivia. *Source: Model simulations*

Due to the improvements in factor productivity, which imply falling production costs, average product prices tend to decrease globally and in the three countries. Large decreases are especially visible in the livestock sector and the processed food sector, while the prices for grains and crops increase on average. The overall increase in prices in grains and crops reflects strong demand growth meeting limited land reserves.

Globally trade becomes more important as the share produced for domestic use decreases, and the importance of imports for consumption increases. In 2050, Vietnam relies on approximately 29% of imports of agricultural products for final demand, whereas in the two other study countries imports are of negligible importance for livestock products and at most 10% for grains and crops. A large share of the demand for processed food is covered by imports in Vietnam (29%) and Bolivia (22%), while in Ethiopia these products are mainly produced domestically. These differences are to a lesser extent already found in 2011. While in Vietnam crop, livestock and processed food systems show a high integration in global markets in terms of exports, again in Ethiopia and Bolivia they are of less importance. Only in Ethiopia, a large increase in exports of meat output over time resulted in a high importance of exports in this sector.

These shifts in production and trade relate to land use changes. Increasing agricultural output globally is driven by both yield changes and cropland expansion. The trend of rapid cropland expansion, especially in Africa and including Ethiopia, is projected to continue, to a lesser extent in South America (Bolivia) and even more limited in Asia (Vietnam), which is also determined by the remaining available suitable cropland in these countries. These changes originate in Vietnam and Bolivia mainly from conversion of unmanaged forests, while in Ethiopia mainly shrubland and savanna grassland are
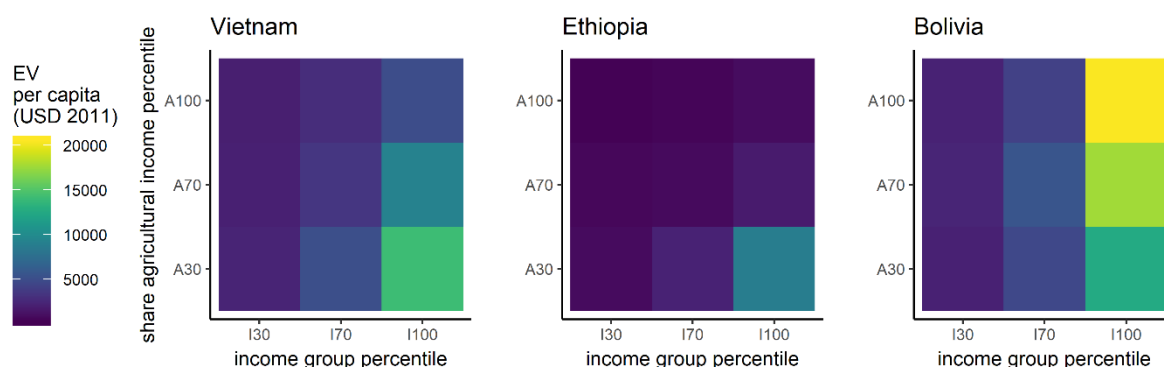
converted. However, the relative expansion in cropland is lower than the increase in population, reducing the available cropland per capita. Cropland use adjusts to meet changes in yields, i.e. generally more land is allocated to crops with negative yield shifts and vice versa.

In response to changes in production and imports, factor demand adjusts. Global factor demand for land increases only little over time, both overall and in the grain and crops sector; with Bolivia following closely these global trends. Likewise, land use in Vietnam changes only marginally, showing a slight decrease over all sectors. In contrast, there is substantial conversion of unmanaged into managed land in Ethiopia. The land devoted as pasture for livestock and meat production increases strongly in Ethiopia, while it decreases or remains unchanged globally and in the two other study countries. The capital stock increases substantially in all three study countries. However, the stock employed in the grains and crops sector falls, reflecting the shrinking importance of crop production in the overall economy. Reflecting increasing scarcity, land prices increase on average over all sectors, for grains and crops, and for livestock and meat in Ethiopia and Bolivia, while in Vietnam it increases only in the grains and crops sector. This relative increase is especially large in Ethiopia in the grains and crops sector. The output increase (as described above) substantially outweighs factor demand change in all study countries, reflecting strong technological progress. These economic wide developments shape the economic impacts from crop yield changes: on the one hand, less available land for food production per capita increases sensitivity to changing yields while, on the other hand, relatively less people draw income from agriculture.

Households effects

As seen from Figure 3 below, all households in our study countries will benefit from the projected GDP increase under SSP2. However, how much a household gains in absolute terms depends strongly on its initial income level and its sourcing. Absolute gains are larger for richer households in all three study countries and, in tendency, decrease with the higher share of agricultural income. The latter reflects that the agricultural sectors show more limited output growth such that capital and labor demand in agricultural increase slower compared to the rest of the economy. Households therefore will shift capital and labor towards other sectors with higher wage and returns to capital. This reallocation comes however at the cost for the remaining households, as a specialization into a shrinking sector implies lower income increases. The negative impact of a specialization into agriculture is true for all household types in Vietnam and Ethiopia, while in Bolivia this is not entirely true for I30 and I70 households, as for them the A70 households benefit most over time instead of A30. In fact, for I30 the household type A30 also gains slightly less than A100 in this income group. Furthermore, for the I100 households in Bolivia the welfare gain strictly increases with increasing share of agricultural income, such that A100 benefits most.

Figure 3: Absolute welfare change in USD per capita of household types up to 2050 for the three study countries

Source: Model simulations

One reason for the lower EV over time for farmers (A100) compared to the other household types is the absolutely lower change in deflated total income for these households (Table 3). The absolute increase in factor income is lower for these households as they have a lower factor income from capital compared to other households. Factor income stemming from capital increases most until 2050, reflecting strong capital accumulation. This benefits households with a higher initial share of capital income. Thus, as agricultural household tend to have larger shares of income from land, the income of non-agricultural households increases in absolute terms more than for other households. In Bolivia, the divergent total deflated income change also explains the deviations in the EV change over time.

Table 3: Absolute factor and deflated total income per capita change household type and country over time

	Total deflated income change								
average	I30_A30	I30_ A70	I30_A100	I70_ A30	I70_A70	I70_ A100	I100_A30	I100_A70	I100_A100
VNM 5653	2720	2556	2483	5630	3900	3304	15068	9809	5405
ETH 1500	934	762	502	2402	893	633	9085	1861	936
BOL 6845	2481	2710	2564	4968	6038	4614	11851	17489	19905
	Factor income change								
average	I30_A30	I30_ A70	I30_A100	I70_ A30	I70_A70	I70_ A100	I100_A30	I100_A70	I100_A100
VNM 1644	300	257	271	1564	922	672	5640	3554	1704
ETH 483	209	147	50	772	287	167	3245	696	317
BOL 2327	377	479	506	1468	1948	1457	4485	6953	8408

Remark: VNM = Vietnam, ETH = Ethiopia, BOL = Bolivia. *Source: Model simulations*

Table 4: deflated total income per capita in 2050 household type and country

	Total deflated income								
	average	I30_A30	I30_ A70	I30_A100	I70_ A30	I70_A70	I70_ A100	I100_A30	I100_A70 I100_A100
VNM	4755	7106	3193	3149	3014	6886	5140	4470	18517	12282
ETH	1319	1824	1065	915	646	2639	1162	903	9827	2381
BOL	6725	9010	3204	3481	3234	6590	7625	5900	16005	21354

Remark: VNM = Vietnam, ETH = Ethiopia, BOL = Bolivia. *Source: Model simulations*

The difference in income also results in different expenditure shares. In Ethiopia, the households' income is lower compared to Vietnam and Bolivia (Table 4), such that the share of income spent on food remains on average largest. In all three study countries, the share decreases on average over time, making them all less vulnerable to price increases for food. Farmers (A100) have in tendency a lower income, which leads to higher expenditure shares for food compared to other household types in all three study countries. Farmers in Bolivia do not always face the highest share of expenditure for food as their income is higher compared to other households.

Household demand per capita increases over time for all commodities on average, by 358%, 781% and 458% in Vietnam, Ethiopia and Bolivia, respectively, whereas, the value of the demand for food increases only by 34% in Vietnam, 162% in Ethiopia and 125% in Bolivia. Decreasing demand for grains and crops is observed on average only in Vietnam, while demand for processed food increases on average in all three study countries. From all food demand, the demand for meat and livestock products increases in all three study countries at a strongest rate being, about twice as high as for processed food products on average. In Ethiopia and Vietnam, the agricultural households (A100) always change demand less than the other households in the same income group. In contrast, in Bolivia this observation holds for the non-agricultural household.

3.2 *Climate change effect*

Economy wide impact

The *bau_CC* scenario underlines that, up to 2050, impacts of macro-economic growth outweigh by far the effects of climate change induced yield shifts. These reduce GDP per capita by less than 0.01% on global average and at most by 0.8% in the three study countries compared to the *no_CC* scenario in 2050. The importance of the agri-food sectors also remains mainly unchanged. Thus, the simulated climate change effects on crop yields generates only slight feedbacks in aggregated indicators for the overall economy, both globally and in the study countries. The production of livestock increases globally (+0.1%) through the climate change induced yield shifts, whereas the production of grains and crops (-0.4%) and processed food shrinks (-0.2%). In the three study countries, the output of all three

sectors declines, with Vietnam showing the largest reduction. As expected, the production of crops with positive yield shifts tends to increase and vice versa, leading, for instance, to an increase of the wheat production in Bolivia. Prices for grains and crops increase globally (+2%) and in the three study countries (4% in Vietnam, 1% in Ethiopia, 3% in Bolivia). For single crops, prices increase can be more substantial, as for instance for sugar cane and beet in Ethiopia (+8%). Prices for crops with positive yield shifts tend to fall.

Import dependency increases for grains and crops both globally and in Vietnam and Ethiopia, whereas in Bolivia it decreases. For single crops, import changes follow the exogenous yield shifts as they counterbalance the resulting domestic production impacts. In Vietnam only, increases in import importance are visible for livestock and meat production. Likewise, in Vietnam, exports relative to production are reduced most in all three agri-food sectors, while this relation increases in Ethiopia for grains and crops and processed food.

Negative yield shifts trigger cropland expansion and thus render land scarcer. Overall, the three study countries show small expansions about 0.1%. Area allocation to crops varies in accordance with the yield shock and trade changes. For example, cropland used for cereal grains nec (not elsewhere classified) decreases most in Bolivia (by 2%) as the positive yield shift (5.4%) allows to produce more on the same area.
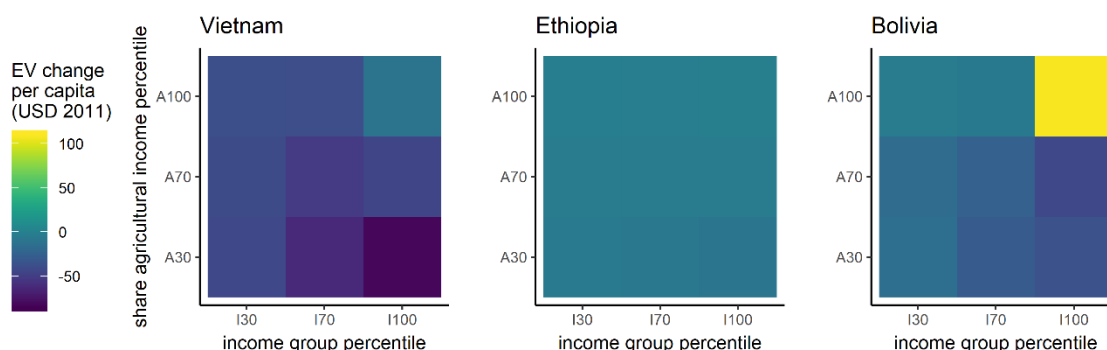
Overall, factor demand globally remains unchanged while it slightly decreases through climate change in Vietnam and Bolivia, and slightly increases in Ethiopia. In contrast to the other two agri-food sectors, factor demand increases in the grains and crops sector on average in the study countries and globally. The percentage increase is lowest in Vietnam compared to the other study countries and to the global average, as in Vietnam demand for all other factors than land decreases. In Ethiopia (0.3%) and Bolivia (0.4%), the lowest increase in demand occurs for land in this sector. Factor prices decrease in all regions on average. However, as land gets scarcer, it is the only factor that faces increasing prices in the grains and crops sector through climate change, besides unskilled labor in Ethiopia of which prices increase by 0.1%.

Household effects

The difference between the *no_CC* and the *bau_CC* scenario reveals that the climate change impact on yields leads on average to a welfare loss for households in all three study countries. The highest losses on average per capita are visible for households in Vietnam (-43 USD), followed by Bolivian households (-22 USD), while Ethiopian households lose on average less (-4 USD). This ranking persists also when comparing single household types between countries. Large variances within one country can emerge when comparing the effect on single household types, as shown in Figure 4. However, all study countries reveal the same pattern, namely that the higher the share of agricultural income is in the

total income, the lower is the projected loss resulting from climate change. Conversely to Vietnam and Ethiopia, in Bolivia the household type with the highest share of agricultural income and the highest income per capita even benefits (+108 USD) from the yield shift. Apart from this, in most cases the absolute welfare loss is higher for richer households in all three study countries. The household type I100_A70 in Bolivia (-42 USD) and I100_A30 in Vietnam (-82 USD) and Ethiopia (-9 USD), respectively, faces overall the highest EV reduction.

Figure 4: Welfare change through climate change for household types in 2050 for study countries

Source: Model simulations

These differences in EV result, inter alia, from changes in household's factor returns. In contrast to the EV, factor returns slightly increases on average per capita in Ethiopia (+0.1%), while it decreases in Vietnam (-0.6%) and Bolivia (-0.2%). Similar to the EV, factor income change rises with increasing agricultural share at constant income per capita level, see Table 5. In fact, it increases most for farmers (A100) or decreases least in all three study countries compared to the other households in the same income per capita quantile. This is because factor returns to land are the only ones increasing through climate change, while others returns tend to decrease overall. They are most relevant for non-agricultural households. Land rents increase through climate change, as demand for food is rather inelastic such that overall demand for food adjusts only slightly, even if production costs rise. The fact that households in Vietnam face comparably larger absolute welfare losses than the same household type in other study countries can be explained by more negative change in factor returns to land. Households with higher per capita income and the same share of agricultural income face more negative factor income changes in absolute terms. Hence, as for the EV, the household types I100_A30 in Vietnam and Ethiopia, and I100_A70 in Bolivia face the largest relative reduction in factor income through climate change.
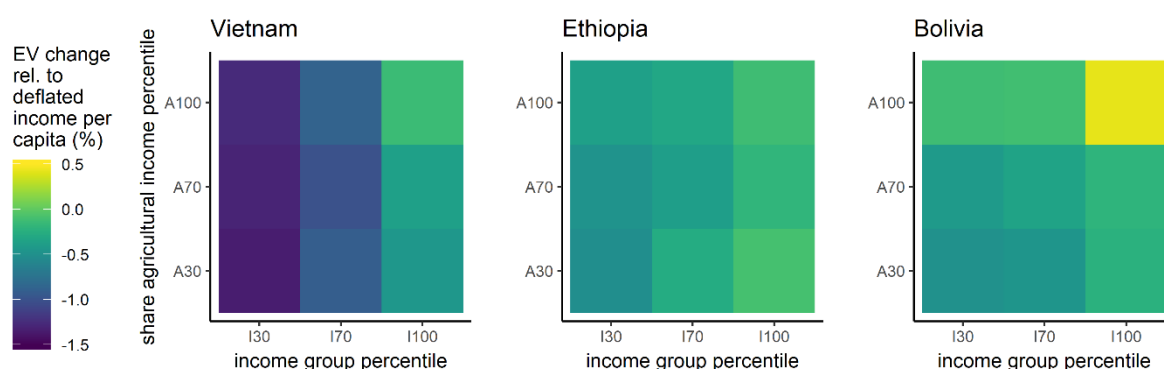
Table 5: Absolute change in factor income per capita through climate change by household and country

	average	I30_A30	I30_ A70	I30_A100	I70_ A30	I70_A70	I70_ A100	I100_A30	I100_A70	I100_A100
VNM	-16	-3	-2	0	-16	-9	-1	-66	-30	-4
ETH	0	0	0	0	-1	1	1	-5	1	2
BOL	-7	-2	-1	5	-8	-7	10	-24	-30	48

Remark: VNM = Vietnam, ETH = Ethiopia, BOL = Bolivia. *Source: Model simulations*

Average demand per capita decreases in all three study countries. The demand for grains and crops, livestock and meat and processed food is reduced through climate change. In Ethiopia and Bolivia, overall demand increases for some A100 households only, while their demand for agricultural products decreases. These households are thus able to consume more from other sectors, whereas the other households consume overall less. Induced by price increase for all three agri-food sectors, the expenditure shares for grains and crops, livestock and meat, and processed food remain nearly unchanged on average through climate change, despite the overall demand decrease.

Figure 5: EV change in 2050 relative to the decoupled income in 2050 per household type and study countries

Source: Model simulations

Setting the absolute welfare loss in 2050 expressed by the EV in USD in relation to the total income deflated by the GDP price index under the *no_CC* scenario in 2050 (Figure 5) shows that richer households, despite higher absolute EV changes, lose less relative to their income. In all income groups, agricultural household types are never the most affected ones. In contrast, mainly non-agricultural (net food buying) households (A30) are identified as most vulnerable to yield shocks. This shows decreasing vulnerability with increasing agricultural share of income. It results from the higher absolute EV change for non-agricultural households combined with decreases in deflated income per capita. In contrast, A100 households face lower absolute EV changes and slightly increasing deflated incomes per capita. As an exception, in Ethiopia, two of the three A70 household groups are the most affected household, namely the I70 and I100 income quantile, while the A100 household is the second most affected. The
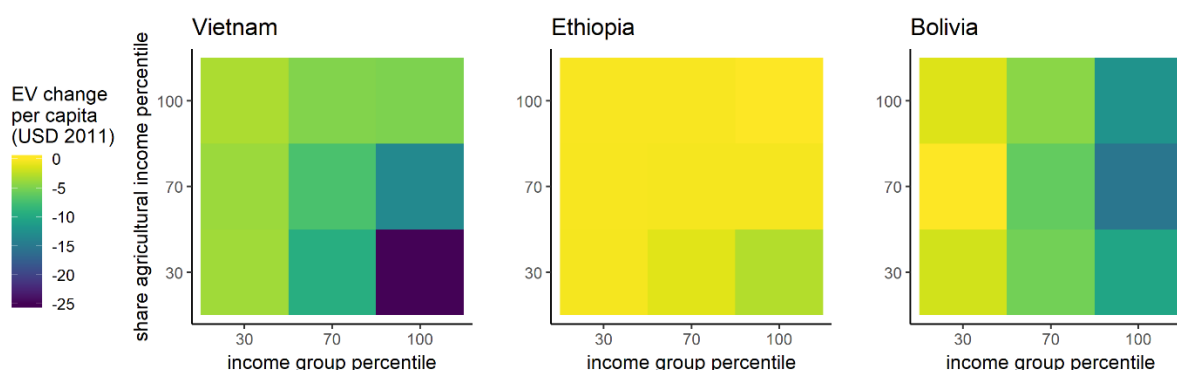
A30 household in Ethiopia is far richer than the other households in the I70 and I100 quantile, which leads albeit the absolute highest EV change to the lowest relative importance. Hence, besides this, farmers face mostly the lowest relative effect.

Additionally, the shares that each household represents in the total population is relevant for the interpretation of the welfare losses. For instance, the household that gains from climate change (I100_A100) represents only 2.4% of the Bolivian population in 2050, while the household type that loses most relative to their initial consumption (I30_A30) represents 11.4% of the total population. Similarly, in Vietnam, the poor (I30) household types represent in sum about 38% of the population, such that the most affected encompass more than one third of the population. In Ethiopia, the relatively most affected household type encompasses 6.5% of the population, with the total poor encompassing 27.6%. Here the middle-income group represents the largest share of the population (41.7%).

3.3   *Comparative static analysis*

Existing studies analyzing climate change induced yield shift introduced the resulting crop productivity changes in a comparative-static setting, i.e. into the currently observed global economy. In order to highlight the contribution of providing a long-run perspective instead, we also conduct a comparative static analysis where population, GDP, demand and production pattern reflect a snapshot of global economy in 2011. As expected, the comparative static analysis shows that, in average, households would face a welfare loss if the cumulative yield changes through climate change up to 2050 would instead happen immediately. However, size and order of welfare changes by household type partly differs from the dynamic analysis. The household type that gained from the simulated climate change effects in Bolivia (I100_A100) faces a welfare loss in the comparative-static case, see Figure 6. In addition, the I30_A70 household now loses more than the I30_A30 in Vietnam. Besides this, the direction of welfare changes and the ranking of households are unchanged from the dynamic analysis and show again that absolute losses in EV are higher for richer households and, in tendency, lower for agricultural households. The divergent results from this general pattern for Bolivia are also found both under in the comparative-static and the long-run analysis. However, absolute changes under a comparative-static setting are considerably than in the recursive dynamic analysis smaller for all household types, including EV changes.
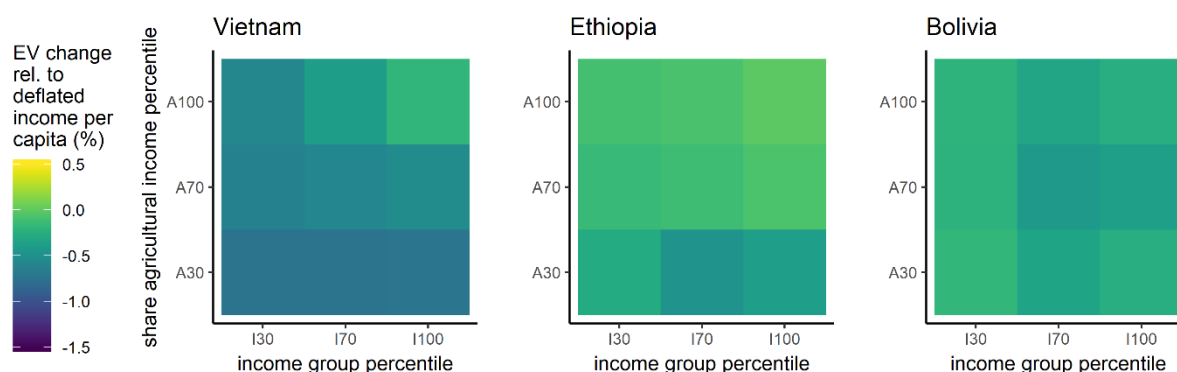
Figure 6: absolute EV change in the comparative static analysis by household type and country

Source: Model simulations

The trend of decreasing relative EV change with increasing agricultural share is also observed here (Figure 7) as absolute and relative EV show the same trend in the comparative static analysis (besides I30_A70 in Vietnam). Thus, it would also result in an identification of non-agricultural households as more vulnerable than others, besides in Bolivia where the A70 household is always most affected. The comparative static analysis does not show that the effect decreases with increasing income per capita, as also many I70 households are among the most affected, while comparing households with the same agricultural share on income.

Figure 7: EV change relative to the decoupled income in 2020 per household type and study countries

Source: Model simulations

The relative EV changes are smaller for most households in the comparative static analysis, i.e. it might underestimate the economic importance of these yield shifts. This might come at a surprise given a decreasing weight of the agri-food sector in the global economy. Only some (rich) households, especially in Bolivia, show higher relative effects under a comparative-static setting, as summarized in Table 6.

Table 6: Absolute difference in relative EV change resulting from the comparative static analysis compared to the recursive dynamic analysis by household type and country

	average	I30_A30	I30_ A70	I30_A100	I70_ A30	I70_A70	I70_ A100	I100_A30	I100_A70	I100_A100
VNM	-0.02	-0.6	-0.68	-0.69	-0.18	-0.42	-0.48	0.28	0.16	0.05
ETH	-0.09	-0.25	-0.32	-0.28	0.2	-0.27	-0.24	0.29	-0.12	-0.11
BOL	0.03	-0.32	-0.21	0.09	-0.12	0.08	0.22	0.02	0.18	0.67

Remark: VNM = Vietnam, ETH = Ethiopia, BOL = Bolivia. *Source: Model simulations*

The comparative static analysis cannot consider that income of the different household types changes at a different pace over time, depending on their respective income sources, which can make households over time relatively more or less vulnerable. Therefore, especially for poor non-agricultural households, the welfare effect is thus underestimated in the comparative-static analysis, while for rich households it is overestimated compared to the recursive dynamic approach. Since the comparative static analysis does not consider GDP growth over time, the importance of the agricultural sector is larger in all three study countries than in the dynamic analysis while total factor productivity remains unchanged. The latter causes overall prices to be higher than in the dynamic analysis. Additionally, income remains at 2011 level, resulting together with the higher prices in larger agri-food expenditure shares. For some household types, especially in Ethiopia, they are twice as high as in the dynamic analysis in 2050. As income over time increases most for non-agricultural households, their income shares for grains and crops show the largest positive difference in the comparative static analysis. Hence, the prices of agri-food are still of larger importance for these households in a comparative-static setting. Only the two A30 household types in Ethiopia with the higher relative negative effect spend less on grains and crops in the comparative static analysis than in the dynamic analysis. In terms of their deflated income per capita, they lose substantially more than other households, as private transfers sent to both households decline through climate change and their factor income decreases. This effect can be explained by decreases returns to capital, which is the main income source of these two household types. Thus, also the slight increase in factor returns to land does not compensate the loss of these households, as it does for all other A70 and A100 households.

In contrast to the dynamic analysis, factor returns to land decrease through climate change in Vietnam and Bolivia as less pressure (also demographic) is on land and more land is still available, making it less scarce, such that land price changes are more muted. In both countries, this results together with the stronger decreasing returns to capital in a relatively higher reduction in factor income for all households. In Vietnam, it decreases percentagewise largest for all rich households. Together with the large EV change this leads to the higher relative effect compared to the dynamic analysis. Since, in Bolivia also factor returns to land decrease for all households, the agricultural households' factor income declines through climate change. As they already had lower income levels on average per capita compared to the other households in the same income quantile, the reduction leads to a

relatively higher EV change than in the dynamic analysis, where their income increases. Increases in factor returns over time in the dynamic analysis result in strong income growth for the agricultural household types (A100) and also for type I70_A70, and I100_A30 and A70. Thus, the EV change is of higher relative importance in the comparative static analysis, even if it is absolutely lower, due to the lower deflated income per capita underlying in the static analysis, as this income rise is not considered.

3.4 *Sensitivity analysis*

The two additional scenarios developed for the sensitivity analysis generally support the previous results of the economic development change induced by climate change. The *mod_CC* scenario results often into a slightly stronger effect than the *bau_CC* in the study countries while the *str_CC* scenario provokes the strongest effect on economic indicators.

The *mod_CC* and *str_CC* scenario result on average in household welfare losses compared to the baseline, which are higher in both scenarios than in the *bau_CC* scenario in Vietnam and Ethiopia, while they are only larger on average in the *str_CC* scenario in Bolivia. More precisely, comparing the single household types between the scenarios shows that the *mod_CC* scenario results in a lower welfare loss only for household I100_A100 in Vietnam and all I100 households in Ethiopia. In Bolivia, only the (poor) non-agricultural households (I30_A30, I30_A70 and I70_A30) lose more of their welfare. As in the *bau_CC* scenario, households with a higher share of agricultural income face lower welfare reductions in the sensitivity scenarios. Again, the exception among the I100 households in Bolivia emerges, so that household type I100_A30 is better off than I100_A70. Furthermore, in the *mod_CC* not only the I100_A100 household gains but also the I70_A100 household faces a welfare gain. In the *str_CC*, in addition household I30_A100 increases its welfare.

The *mod_CC* yield shock is more negative for 4 of the 8 crop aggregates in Vietnam, explaining the reduction in EV compared to the *bau_CC* scenario. The decrease in total deflated income exceed on average and for all non-agricultural households under the *bau_CC* scenario. Thus, most households increase expenditure for the agri-food sectors due to higher prices, an effect which is negligible or even reversed only for a few households.

In Ethiopia, the yield shock under *mod_CC* is less negative for all crop aggregates but cereal grains nec, which decreases by 2.1 pp. This aggregate includes main staple crops of Ethiopian diets such as maize and sorghum, which remain besides 'vegetables, fruits and nuts', and 'food products nec' the agri-food products that are most demanded in 2050. Given the large demand, the price increase (+5%), which is considerably stronger than for all other crops, affects household expenditure visibly. Even if factor income rises for all households, improving their deflated income compared to the *bau_CC* besides A30 households, nearly all households increase their expenditure for grains and crops in both scenarios, while for meat it is mainly reduced. The discussion underlines the importance of a

disaggregated analysis of several food products, as staple crops matter more in poorer countries and household groups and can be differently affected by climate change.

Poor non-agricultural households and the I70_A30 lose more in the *mod_CC* than in the *bau_CC* scenario in Bolivia. This is caused by increasing prices for most crops compared to the *bau_CC* scenario. This increase lets poor non-agricultural households increase their expenditure share for grains and crops, and processed food more than in the *bau_CC* scenario. Whereas, the majority of the households change expenditure for food like in the *bau_CC* scenario, especially for meat. Agricultural households slightly lower their food expenditure because of their increasing income. For richer households, price increases in grains and crops are of less importance as they consume more processed food and livestock.

Setting the EV change in relation to the deflated income of each household type in 2050 shows in both scenarios mainly the same effects as in the *bau_CC* scenario. In Ethiopia, some deviations from the *bau_CC* arise in both additional scenarios, as among the poorest households (I30), the A70 household is most vulnerable, followed by the A30 household. The same is observed among the I100 households, opposite to the *bau_CC* scenario. In Vietnam and Ethiopia, all households are worse off in the *mod_CC* and the *str_CC*, besides rich households which partly face an absolute welfare gains in the *mod_CC* scenario (Vietnam: I100_A100 and Ethiopia all I100). In Bolivia, in both scenarios, some households are better off and others are worse off compared to the *bau_CC*. On average though, in the *mod_CC* households are better off, while in the *str_CC* they are worse off.

4   Discussion

The baseline constructed using the SSP2 data for GDP and demographic developments are in line with Popp et al. (2017). Most prices for agricultural products fall in the baseline until 2050. Furthermore, the trade with agricultural products increases in the baseline as also found in their analysis. Similarly, the authors find cropland expansion to occur at the expense of unmanaged forest, which is also found in our study. The location of cropland expansion results similarly in both analyses, being largest in Latin America and Africa. Consequently, our results show similarities with the Fricko et al. (2017), who study SSP2 developments. They find livestock demand to increase globally which can also be seen here, as production and consumption increase.

The effect of the yield shift induced by climate change on different household groups are similar to results found by previous studies. Hertel et al. (2010) analyze the agricultural impacts of climate change in 2030 on global commodity prices, national economic welfare, and the incidence of poverty of 7 household strata in 15 developing countries in the economic setting of 2001. The effects are simulated using the static GTAP model, by including low, medium, and high productivity shifts for six commodities in the developing countries and the rest of the world by 2030. The authors determine costs

of living and earnings as two channels of poverty impacts. Thus, increasing food prices result in falling poverty rates for households specialized in agriculture and rising rates for non-agricultural households (especially urban wage earners). This is in line with our results, where farmers are absolutely less affected through climate change. Similarly, our results align with Skjeflo (2013), who simulates the importance of access to the markets on household vulnerability to climate change in 2000 in a CGE model for Malawi by inducing productivity shocks and an exogenously adjusted global price for maize from 2030. Skjeflo (2013) finds that large farms with access to markets can actually benefit from the yield reduction through increased maize prices. According to her analysis, urban poor and small-scale farmers are most vulnerable. This is because these households do not exploit increasing returns to land and agricultural labor while they have high expenditures for food and face increasing food prices. This is in line with our results of the dynamic analysis that show that some farmers even gain, and the other agricultural households at least lose less than the other households in their income group. While the analysis by Skjeflo (2013) is focused on Malawi only, our study assesses further countries, applying country specific climate change shocks with global coverage. Thus, our analysis verifies that the patterns are transferable to other LICs and LMICs. However, the size of the effects deviates from our analysis, our findings being considerably smaller in both the comparative and the recursive dynamic analysis. Differences emerge inter alia as the price and yield shocks are higher in Skjeflo (2013) and the EV is calculated relative to the initial household expenditure while we use the total deflated income. Hallegatte and Rozenberg (2017) study the effects of climate change on households in 92 countries using a bottom up approach (microsimulation). The analysis is based on SSP4 and SSP5 upon 2030. Hallegatte and Rozenberg find that impoverished people are relatively more affected than the population average and that lifting people out of poverty is a good way to reduce future impacts. However, they name as a limitation of their study that they do not consider investments and trade. The latter is identified by Xie et al. (2019) to have a large impact on food security (especially if distorted) as it transmits price signals.

The sensitivity analysis shows that the results are robust and that not only the severity of the yield shock matters but also which crops are affected. Hirvonen et al. (2015) find that cereals contribute on average 60% to the energy intake of Ethiopian households. Thus, the small variety of staple crops in their diets makes Ethiopian households especially vulnerable to the yield shock. This is in line with Aksoy and Isik-Dikmelik (2008), who state, that a more diverse food basket decreases vulnerability to price changes. Since, this increases substitutability and flexibility to adjust.

The integration of yield shifts as the only impact of climate change on the agricultural sector in the model misses other potential impact channels of climate change in the agri-food nexus. Consequences on health, migration and food security stemming from catastrophic climate change events such as extreme weather events, weed and disease pressures, tropospheric ozone, and sea-level rise, are not

captured in our model assessment. Catastrophic climate change events might exacerbate losses in land productivity, as pointed out by FAO (2018). For example, sea-level rises could affect arable land near coastlines. Thus, better quantification of impacts on crop yields and including more climate change impacts such as for instance sea level rise (see Nauels et al. (2017)) will improve the representation of climate change in this analysis. In our simulation, this could be especially relevant for Vietnam as a country with long sea borders. Furthermore, rising temperatures might decrease labor productivity especially in the agricultural sector, as this work is carried out mainly on the field, exposed to the weather (Kjellstrom et al., 2009).

We assess average yields over a year. However, interannual scarcities in crops as, for instance, before each harvest (Vaitla et al., 2009) are also of large importance for vulnerability. Similarly, local differences in yields among regions in a country can result in differentiated effects for households depending on their residence. Wossen et al. (2018) find poor households to be especially vulnerable to price and climate variability, exacerbating poverty and inequality, in their assessment for Ethiopia and Ghana. Likewise, Ahmed et al. (2009) determine urban wage earners to be most vulnerable to volatile climatic events and Ahmed et al. (2011) find overall a large increase in Tanzanians poverty if precipitation gets more volatility. Furthermore, climate variability increases uncertainty. Nevertheless, we do not consider risk and risk behavior of firms which could especially in LICs play a crucial role in production decisions under climate change and how this affects markets, and households' income. We assume that land is owned by households working in agriculture. This ignores the actual institutional settings in different countries, which make households owning property rights to land benefit from increases in land rents rather than those producing with this factor. Moreover, we assume complete access to the market for all households. The underlying household data is built such that goods are accounted for as income (based on the market price of the products), which is then spent on these goods, even if they are produced for own consumption. Thereby, we assume that all goods dedicated to consumption are sold and bought from the market. In case of subsistence farmers, the interpretation of our results can thus be misleading. In reality, for subsistence farmers with no access to markets a negative yield change would directly affects the amount harvested while they do not benefit from increasing prices, threatening their food security. Furthermore, catastrophic events can reduce food availability as transport is distorted impeding households from selling or buying products (Ziervogel and Ericksen, 2010). Additionally, pressure on land can be raised through land-based mitigation efforts (Doelman et al., 2018) affecting the wellbeing of households. We refrain from including mitigation and adaptation strategies and their consequences in order to focus on an unmitigated shock on crop yields. Due to data availability, the Ethiopian households represent mainly rural households, thus urban households are underrepresented for this study country. However, according to the census 2007, more than 83% of the population lived in rural areas (CSA, 2008). In 2019, it was still 79% of the population according to World Bank (2020), such that this survey still represents a large part of the population.

This study provides new insights in the context of vulnerability assessments of households regarding climate change effects. The sole assessment of the effects on macroeconomic indicators (GDP) can be misleading, as its response to the limited crops yield shocks is small. Previous assessments which have considered households level effects of yield shifts used mainly comparative static modeling frameworks. However, for such climate change assessments the demographic dynamics are of large importance as over time consumption patterns change and the importance of agricultural sectors decrease. Furthermore, pressure on land increases and thus mitigation options are reduced, and intensification potentials decrease. In addition, income develops differently over time depending on the source of income, determining vulnerability. This study determined again the importance of disaggregation of different household types, as on average all households lose through climate change, which does not represent the variances between household types and would not reflect that some even gain from climate change. Yet, this is important to target climate change vulnerability policies to the households most in need.

5   Summary and conclusion

We assess the effects of yield shifts induced by climate change on low and low middle-income countries in terms of the economic changes (production, trade, demand) and of the welfare of nine household types distinguished by level and share of agricultural income in 2050. To this end, we apply a recursive dynamic CGE model with household detail, which draws on the SSP2 projections for GDP per capita, population and workforce data, and include yield shifts for 8 crop aggregates. Additionally, we perform a sensitivity analysis to test the robustness of the results, considering the uncertainty of the effects of the climate change on yields and a comparative static analysis to disentangle the difference to our dynamic long run model. The results show that effects vary between the nine household types and that not only the level of income is of relevance for the vulnerability to climate change but also the factor endowment. We show that agricultural households are both absolutely and relative to their income in most cases the least affected ones and that richer households face absolutely larger effects; while relative to their income the poor are the most affected. The sensitivity analysis shows that results are robust and that the yield shock on the staple crops largely determine the effect on the households (especially for the poor).

Thus, it is important to disaggregate the yield shifts and different household types and to take not only income levels, but also other aspects such as agricultural income share into account. Various studies have identified that higher food prices can benefit agricultural households. In addition, our modeling framework gave new insides, especially into the long run development. It shows both in under- and overestimations of vulnerability for some household types in a comparative-static analysis with an otherwise identical model set-up, a consequence of missing key dynamic developments in

comparative-statics, such as varying importance of sectors, sector specific productivity growth, income dependent consumption change.

With the limitations and uncertainties in mind, our results stress the need for a differentiated assessment of climate change impacts. Even with this study, limited to nine household groups and based on two-dimension points, the results clearly show the divergent consequences of climate change on households. Across countries, consequences were found to be comparable, while remaining differences show the need for country-specific strategies considering regional priorities for mitigation and household specific needs. Differentiated policy set-up enable countries to mitigate negative impacts from climate change while working towards the SDGs both globally and in their country-specific contexts.

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Annex

Table A.1: country aggregation

Aggregate	Country
Vietnam	Vietnam
Ethiopia	Ethiopia
Bolivia	Bolivia
ASIAN	Brunei Darussalam, Cambodia, Indonesia, Lao People's Democratic Republic, Malaysia, Philippines, Singapore, Thailand Rest of Southeast Asia
Rest_COMESA	Egypt, Kenya, Madagascar, Mauritius, Rwanda, Uganda, Zambia, Zimbabwe, Rest of Eastern Africa
Mercosur	Argentina, Brazil, Paraguay, Uruguay,
Rest_ANDEAN	Chile, Colombia, Ecuador, Peru, Venezuela
REST_CAFTA	Costa Rica, Guatemala, Honduras, Nicaragua, El Salvador, Dominican Republic, Rest of North Africa
ROW	Oman, Israel, Rest of Oceania, Hong Kong, Taiwan, Rest of East Asia, Bangladesh, India, Nepal, Pakistan, Sri Lanka, Rest of South Asia, Rest of North America, Rest of South America, Panama, Rest of Central America, Jamaica, Puerto Rico, Trinidad and Tobago, Caribbean, Belarus, Russian Federation, Ukraine, Kazakhstan, Kyrgyzstan, Rest of Former Soviet Union, Armenia, Azerbaijan, Georgia, Bahrain, Islamic Republic or Iran, Jordan, Kuwait, Qatar, Saudi Arabia, Turkey, United Arabic Emirates, Rest of West Asia, Morocco, Tunisia, Rest of the world
USA	United States of America
Rest_OECD	Australia, New Zealand, Japan, Korea, Canada, Mexico, Switzerland, Norway, Rest of EFTA
EU28	Austria, Belgium, Cyprus, Czech Republic, Denmark, Estonia, Finland, France, Germany, Greece, Hungary, Ireland, Italy, Latvia, Lithuania, Luxembourg, Malta, Netherlands, Poland, Portugal, Slovakia, Slovenia, Spain, Sweden, United Kingdom, Bulgaria, Croatia, Romania
Rest_Sub-Saharian Africa	Benin, Burkina Faso, Cameroon, Cote d'Ivoire, Ghana, Guinea, Nigeria, Senegal, Togo, Rest of Western Africa, Central Africa, Southern Central Africa, Malawi, Mozambique, Tanzania, Botswana, Namibia, South Africa, Rest of South African Costums
China	China
CEFTA	Albania, Rest of Eastern Europe, Rest of Europe

Source: Aguiar et al 2016