Should long-term climate change adaptation be focused on smallholders?

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Abstract

Smallholder agriculture employs the majority of the global poor and produces substantial shares of food in developing countries while also being highly vulnerable to environmental change. This makes it a focus of numerous policies for increased productivity and climate change adaptation. Given demographic and economic processes that are likely to reduce smallholder prevalence, how justified is this focus from a long-term perspective? We estimate future global smallholder distributions using historical trends and demographic projections and calculate indices of its future share of climate change impacts. While past trends of decreasing farm size are likely to reverse in Asia and slow down in Africa, we project smallholders will continue to occupy substantial shares of rural populations and cultivated land and bear a sizable portion of climate change impacts, amounting for about 33% (25%) of an index of human exposure to 1 °C (2 °C) warming. However, increased economic possibilities in rural areas can rapidly attenuate these assessments.

1. Introduction

Three-fourths of the rural poor in developing countries are smallholder farmers, who cultivate small parcels of land with little use of modern inputs or technologies, often for subsistence. Improving and sustaining smallholder productivity is considered essential for continued poverty alleviation and food security (Lobell \textit{et al} 2009, Godfray \textit{et al} 2010, Mueller \textit{et al} 2012, Zhang \textit{et al} 2016).

Climate change is expected to have severe impacts on global Agriculture, and smallholder agriculture in developing countries is likely to be particularly vulnerable (Morton 2007). Moreover, a range of economic, institutional, and behavioral factors are likely to constrain autonomous smallholder adaptation (Fan \textit{et al} 2013, Di Falco \textit{et al} 2011, 2019, Fishman \textit{et al} 2013, Thornton and Herrero 2014, Blakeslee \textit{et al} 2020). As a result, enabling smallholder adaptation has become a major focus of international development discourse\(^4\).

Is the focus on adapting smallholder farming justified? Here, we examine this question from a long-term point of view. We ask whether, by the time the brunt of climate change impacts is realized, demographic and economic trends may diminish the dominance of smallholder farming to the extent that they may make them of secondary importance for poverty eradication and food security.

\(^4\) For example, in justifying the rationale for starting the Adaptation for Smallholder Agriculture Program, The International Fund for Agricultural Development (IFAD) notes that: ‘…The challenge climate change poses to the world’s 500 million smallholder farms cannot be overlooked… Avoiding and managing climate risk is a prerequisite for poor rural people to move out of poverty…’ (IFAD 2015).
The question we raise is distinct from the ongoing debate about the shorter-term effectiveness of focusing on smallholder productivity as an economic development strategy (Collier and Dercon 2014). However, it is equally important for policymaking because policies targeting smallholders need to be designed in a specific manner and may take long time periods to generate impacts (World Bank 2007, Jack 2013). The implicit assumption that smallholder predominance will persist sufficiency long to justify such policies appears to be seldom discussed in agricultural policy debates. This is likely due to a range of empirical challenges, including the dearth of high-quality data on the current numbers and distribution of smallholders (Lowder et al 2016); uncertainties involved in projecting demographic changes; and the difficulty of modeling the complexity of the processes at play.

Projections of the future prevalence of smallholders need to reflect the balance of two dominant but counteracting-processes. On the one hand, high fertility rates (FR) in rural areas of developing countries may continue to increase population sizes over the coming decades, but on the other hand, rapid demographic and economic changes are likely to shift increasing fractions of this population away from rural areas, and even within rural areas, from farm to nonfarm employment. The net effect of these opposing trends on the total number of farming households, and therefore on the distribution of landholdings, could either increase or decrease the shares of land and the farming population that are occupied by smallholders.

We perform a quantitative projection of the future (up to 2050) prevalence of smallholders in developing countries that considers these two trends. As far as we are aware, this is the first attempt of this nature to be made on a global scale. The model projects the share of smallholder farming in terms of both the number of farmers and in terms of cultivated land. These two indicators are of independent importance, with the former being vital for poverty reduction and the latter for food production. We then combine model results with climate change projections to estimate the share of warming, appropriately defined, that will be borne by smallholders, measured through these two indicators.

It is important to emphasize that data gaps and other uncertainties make it challenging to conduct a robust projection of the future number of smallholders. Rather than as a definitive numerical prediction, we view our analysis as an accounting framework around which long-term policy planning for smallholders can be discussed, using the best available demographic and economic evidence. Our goal is to facilitate a more structured discussion of the merit of long-term adaptation policy focus on smallholders, the accuracy of which can be further improved as new data becomes available.

Several papers have analyzed the current and past distributions of smallholders. The High-Level Panel of Experts of the Committee on Food Security (HLPE 2013) found that 85% of the world’s farms are smaller than two hectares (using data from the 2000 world census of agriculture (WAC) for 81 countries). In Africa (using data for 14 countries), 80% of holdings are smaller than two hectares in size and operate about 25% of the agricultural land. Nagayets (2005) find similar results. A more geographically (sub-national) detailed assessment of smallholders numbers in the developing world is offered by Samberg et al (2016), who estimate 380 million farming households hold less than five hectares but hold a third of agricultural land and produce more than 70% of the food calories in these regions. Masters et al (2013) discuss the increasing diversification of global agriculture that is driven by urbanization and commercialization. They describe a decrease in farm sizes in Africa and Asia from 1950 to 2010 that they assert will continue in Africa but reverse in Asia. In contrast, Jayne et al (2016) suggest that in Africa, the share of land accounted for by smallholders (defined in this paper as those cultivating less than five hectares) is declining.

2. Outline of our approach

Our framework considers three basic processes that can affect the future numbers of farming households, and therefore the distribution of landholdings. All three processes have accompanied the historical economic development of most industrialized countries (see, for example, Gollin et al 2002) and are evident in changes currently taking place in developing countries (Masters et al 2018). Historical data can therefore be used to project the future magnitude of these trends.

The first process is the increase in the size of the overall population, especially in rural areas, which is likely to continue in many developing countries into 2050. The second is migration to cities, which will increasingly shift the distribution of the population from rural to urban areas. The net impact of the two processes will determine the size of the rural populations, or more specifically, the number of rural households in each country, which will, in turn, determine the distribution of agricultural land. The number of rural households can be projected forward based on widely used projections of future rural and urban populations (UN, Population Division, 2014). Projecting the number of rural households engaged in farming, however, requires accounting for a third process, the structural transformation of the rural economy, through which labor gradually shifts from agriculture to the manufacturing and services sectors (Haggblade et al n.d.). Both the magnitude and the nature of this transformation can have substantial
impacts on the distribution of agricultural landholding.

Shifts to nonfarm income generation can occur through formal or informal off-farm employment, a common practice in developing countries, or through the opening of nonfarm small or medium enterprises. Each of these transitions is a complex process with its own drivers, outcomes, and implications for resilience. However, for the purposes of our simple accounting framework, we merely distinguish between two stylized pathways through which a household can reduce its agricultural labor share: in the first pathway, some members of each household shift to non-agricultural activity, but the household’s land continues to be cultivated by other household members, while in the second pathway, the entire household leaves cultivation altogether, and its land becomes cultivated by another household. In our projections, we consider two extreme scenarios in which structural transformation is entirely dominated by one of these pathways and refer to them as scenarios A (only some household members leave farming) and B (only entire households leave farming). In scenario A, the structural transformation has no effect on the average landholding size or on the shares of smallholders in the farming population and in cultivated land. In scenario B, the mean landholding size increases, and the shares of smallholders decline. Of course, the actual future trajectory is likely to be a combination of these two possibilities, and our analysis highlights the importance of the distinction for projections of land distributions.

Having projected the number of rural households engaged in farming and assuming that the overall size of cultivated land does not change, we proceed to calculate the average size of an operational landholding. Of course, the fragmentation and consolidation of land that accompanies population growth, migration to cities, and exit from farming can be extremely complex and highly variable from country to country, and both processes remain imperfectly understood empirically, especially on a global scale. Moreover, projecting the future size of an average operational landholding only provides a first-order indication and may obviously fail to capture the higher moments of the land distribution. Nevertheless, to make progress, our analysis takes a first step in making such projections by extrapolating from projected averages to the full distribution on the basis of assumptions, largely backed by current data, on the form of the land distribution. We use the term operational holding to distinguish effective management and cultivation, in which we are interested here, from formal ownership. Changes in land ownership, rather than management, are much harder to project but are secondary for the purposes of this analysis.

3. Results

3.1. Current numbers of smallholders

Figure 1 displays the fraction of holdings (top) and arable land (bottom) that belong to smallholders in those countries for which data is available from the World Census of Agriculture (WCA), between the years 1998 and 2013 (FAO 2001, 2013, 2021). The share of holdings that are smaller than two hectares varies between 20% and 100%, with a mean of 66%. The share of arable land belonging to these holdings varies between less than 1% and 98%, with a mean of 28%. These wide ranges of variation within low and middle-income countries highlight the complexity of modeling smallholder numbers.

3.2. Past trends of smallholders numbers

Before making future projections, we report past trends in smallholder fractions by using data from countries \(n = 49\) for which more than one observation is available in the WCA (figure 2). For 25 countries, data were available for more than one year, allowing us to see trends. While the sample is small, we note that almost 70% of the countries in this group display an increase in the share of smallholdings.

3.3. Future projections without structural transformation

We begin with projections of average landholding size (figure S5 available online at stacks.iop.org/ERL/16/114011/mmedia) that do not account for structural transformation. According to our model, the current average landholdings are still a bit bigger in sub-Saharan Africa (SSA) than in Asia (1.8 hectares in SSA vs. only one hectare in Asia), but with time, we project the average holding size to decrease in SSA and increase in Asia. In SSA, we project the increase of rural population to dominate the projected decrease of rural employment in agriculture, eventually causing a decrease in mean plot size (figure 3).

The global numbers of smallholders are likely to remain relatively stable at about 2.2–2.4 billion. In Asia, they are projected to decrease by 17% to about 1.5 billion by 2050, while in SSA, to increase by 29% to about 708 million by 2050 (figure S6). Figure 4 displays the projected shares of smallholders in the total (green) and rural (orange) population (also displayed geographically in figure S7). By 2050, the share of smallholders in the total population is projected to decrease to 26% overall in the countries in our sample (a decrease of 33% from current levels), 29% in Asia, and 28% in SSA.

The share of smallholders in the rural population is projected to reach 74% overall in the countries in our sample, an insignificant change from 2020 levels. This stability is in large part a result of the stability of
the number of rural households, and thus land distributions, which in turn reflects an approximate balance of rural population growth and urbanization, but masks substantial geographical heterogeneity that reflects regional disparities in the projected pace of urbanization. While in 2020, the share of smallholders in the rural population is still slightly lower in SSA than in Asia, these shares are projected to both reach about 75% by 2050, as they increase in SSA and decline somewhat in Asia.

The global share of arable land cultivated by smallholders is similarly projected to remain stable in the overall sample over the coming decades, at around 25%. Asia and SSA are projected to reach similar fractions by 2050 but through a decline in Asia and an increase in SSA (figure 4).

### 3.4. Accounting for structural transformation

Projections that account for structural transformation through scenario B are represented by dotted lines and bars in figures 4, 5, S5 and S6 (also displayed geographically in figure S8). Projected numbers of smallholders are naturally smaller in this scenario and decrease by 16% overall to 1.7 billion people,
as compared to a stable trend in scenario A. The contrast in the sign of the trends in Asia and in SSA is retained.

The share of smallholders in the rural population is projected to decrease in the whole sample and in Asia, and to increase in SSA. Their share in the total population is expected to decrease to around 20% overall and in Asia and 25% in SSA (figure 4).

The projected share of arable land cultivated by smallholders in scenario B is depicted by the purple dotted line in figure 4. Accounting for structural transformation leads it to decline substantially overall, with only 10% of arable land being cultivated by smallholders in 2050. Since projections in Scenario B rely on an extrapolation of the global historical rate of decline in agricultural rural employment
Figure 3. Schematic representation of projected trends of the rural population (source: UN World Urbanization Prospects database), rural employment in agriculture, average plot size, and the share of small (<2 Ha) plots (source: model projections). Arrows represent signs of projected trends. Dotted arrows represent trends that are zero or negative.

3.5. Application to climate change adaptation
We combine the projections presented in earlier sections with climate change scenarios to estimate the future share of exposure to the increased temperature that is likely to be borne by smallholders in terms of both population size and land cultivation (see the section 5 for definitions).

The estimated share of climate change exposure is reported in figure 5 (solid bars). Between 2020 and 2050, the share of exposure to an increase of over 1 °C that will be borne by rural populations (out of the total population) is estimated to be about 40%, and the share of exposure to an increase of over 2 °C increase is estimated at about 32%. The share of 1 °C exposure of the total exposure projected to be borne by smallholders is projected to be about 31% (35% in Asia, 35% in SSA) of exposure by the overall population, and the share of 2 °C exposure is projected to be about 23% (22% in Asia, 46% in SSA). The corresponding shares of smallholder’s exposure, calculated in terms of arable land rather than population, are projected to consist of 26%, for 1 °C exposure (38% in Asia and 24% in SSA), and 18% for 2 °C exposure (24% in Asia and 30% in SSA). Accounting for structural transformation (scenario B) can reduce these shares (figure 5, dotted bars). For example, smallholders share of total 1 °C exposure is projected to be, in scenario B, 25% (27% in Asia and 28% in SSA), and 18% of the 2 °C exposure (16% in Asia and 28% in SSA) (figure 5).

4. Discussion and conclusion
Over the next few decades, smallholder agriculture will remain highly relevant for global poverty reduction (as a source of income for major shares of the
Figure 4. Left: projected share of smallholders in the total (green) and rural (orange) population (green), by region. Right: the projected share of arable area cultivated by smallholders. Solid lines represent projections that do not account for structural transformation. Dotted lines represent projections that account for the structural transformation of the rural economy under scenario B (see text for details).
population) and food security (as a share of overall cultivated land). Even though the share of smallholders in the total population is declining, by 2050, they are still projected to consist of about 30% of the population in Asia and in SSA. Similarly, smallholders will cultivate over 30% of land in both Asia and SSA. If smallholders continue to achieve higher yields, their share in food production will be even higher. These projections are also reflected in the future share of climate change exposure expected to be borne by smallholders. Combining our projections with country level warming projections suggests that substantial shares of climate change exposure are likely to be still borne by smallholders, amounting to more than 30% of human exposure and 26% of land exposure to 1 °C warming.

Overall, these results suggest that there is merit in maintaining a long-term policy focus on smallholder agricultural productivity and climate change adaptation from both a food security and poverty eradication perspective. Policies that are focused on smallholders require different emphasis and design than those focused on larger land-owning farmers due to their unique socio-economic characteristics and challenges. Neglecting to account for these challenges in long-term agricultural policy may, therefore, neglect substantial shares of rural populations and food production and an even larger share of the global poor.

At the same time, our results also show that accounting for employment shifts outside of agriculture in accordance with past trends will likely decrease the shares of smallholders in food production and climate change exposure. Under a scenario that accounts for such shifts, we project smallholders to still constitute a relatively significant share of the population (21% in Asia, 26% in SSA), but their share of cultivated land will decline substantially to about 10% in SSA and in Asia. Even modest increases in the rate of employment shifts away from agriculture within rural areas (keeping urbanization rates fixed) results in substantial reductions in the prevalence of smallholders in 2050 in terms of both population and area. Thus, even within the confines of conventional rural population projections, our analysis highlights the sensitivity of future farm size to the rate of structural transformation in rural areas. Increasing the rate of structural transformation within rural areas has the potential to alter our benchmark projections substantially and dramatically reduce future smallholder numbers. Policy interventions that help to increase the rate of structural transformation within rural areas have the potential to alter our benchmark projections substantially and dramatically reduce future smallholder numbers. Interventions of this kind can include encouragement of service or manufacturing firms to set up in rural or peri-urban areas, which many governments pursue through easing various institutional constraints (like land-use regulation) or the setting up of special industrial zones. If effective, a policy focus of this kind can reduce the need to focus on long-term poverty alleviation or climate change adaptation policy on smallholders. However, even if rural populations leave farming at an increased rate, this does not guarantee an increase in the scale of farming unless land policy ensures that land belonging to households that turn to off-farm employment is consolidated through efficient land ownership or rental markets. If such markets do not operate efficiently, small-scale cultivation may continue to dominate food supply.

Two important qualifications are in order. First, we measure the prevalence of smallholders through the share of the population that resides in households with landholdings below a certain threshold. Within this framework, we have made a distinction
between two stylized, extreme scenarios. In the first one, such shifts are carried out by some workers in each household (scenario A), and in the second, they are carried out by entire households. Even though in scenario A the number of smallholders is higher than in scenario B, smallholders in scenario A reside in households with non-agricultural income sources, so each of them is in some sense less dependent on agriculture for their income. Our measures of exposure do not account for this element. Of course, scenarios A and B represent two extreme possibilities, and we expect realistic future trajectories to lie somewhere between the two. Future studies should also attempt to include processes like land acquisition (Jayne et al. 2016), and use country or region-specific information if such data are available in the future.

Second, since our model projects smallholders’ share in the population, it does not necessarily fully account for their share in terms of deprivation, as they are often an extremely vulnerable population. In addition, the sociopolitical and economic constraints faced by smallholders are likely to be intensified by climatic change, and smallholders are projected to be pushed into increasingly riskier conditions in the future (Vadjunec et al. 2016). It is therefore vital to retain a focus on smallholders in policy discussions for at least the next two to three decades.

Based on our model, it seems safe to say that smallholder populations, and their share in the overall population, have already peaked in Asia (Masters et al. 2013). Higher rates of shifts outside of agriculture will only strengthen this conclusion. Our projections for SSA are less conclusive and sensitive to the modeling of employment shifts outside of agriculture. It is unclear whether SSA may eventually display a similar trend to Asia. This depends on whether SSA might follow a similar trajectory of economic development to the one taken by Asia, especially in terms of the relative roles of agriculture and industry, which remains a debatable proposition (Collier and Dercon 2014, Rodrik 2014).

5. Methods and data sources

5.1. Data and definitions

The countries included in this analysis consist of low and middle-income countries as classified by the World Bank (2016). For much of the analysis, we focus on two geographical regions: SSA and Asia (table S1). The analysis makes projections for the period 2020–2050 and is conducted at decadal time steps.

The HLPE found that the most commonly used measurement for defining smallholders is their farm size. A two-hectare threshold is frequently used to label farms as small (Bosc et al. 2013), and we follow this convention here. Data on the amount of arable land in each country were obtained from the Food and Agriculture Organization (FAO)’s Agri-Environmental database (FAO 2016). For some parts of the analysis, we also use data on arable land from the World Development Indicators (WDI) database of the World Bank (2016). Arable land includes land under temporary agricultural crops, temporary meadows, market and kitchen gardens, and land that is temporarily fallow.

Country-level data on past and future projections of the total and rural population (1950–2050) was obtained from the UN World Urbanization Prospects database (UN, Population Division 2018). Historical data was also obtained from the World Bank’s WDI database (World Bank 2016).

Data on historical and projected FR were obtained from the UN World Population Prospects (2019). Historical FR were also taken from the World Bank’s World Development Indicators Database (World Bank 2016). Data on employment rates were obtained from the International Labour Organization (2016) and the World Bank (2016).

Historical data on the distributions by number and area of holdings of different sizes were obtained from the WCA rounds 2010 2000, 1990, 1980, and 1970 (FAO 1997, 2010, 2021)\(^5\).

5.2. Basic model

To project future smallholder populations, we make use of future projections of rural populations and use a simple model of the distribution of landholding sizes in each country. The model is highly stylized but performs reasonably when tested on available past data (see below). It relies on three simplifying assumptions: (a) the number of agricultural landholdings corresponds to the total number of rural households; (b) arable land in each country remains constant; (c) the form of the distribution of landholdings assumes a uniform functional form across countries and time (we selected an exponential distribution form, as we explain below). We emphasize that while these are highly stylized assumptions, the paucity of both historical data on the numbers of smallholders and of well-established models of smallholder population dynamics require us to make rather aggressive assumptions in order to make progress. The details of our calculation are described below.

5.2.1. Number of rural households

To determine the number of rural households \((H_{c,t})\) in each country \(c\) and time period \(t\), we first estimated the average household size in that country and year on

\(^5\)In several countries the data on farm size distributions is confined to only small farms. However, the total number of holdings is available, but the larger farms are aggregated in larger size groups. We only used data that includes information about holdings specifically smaller and larger than the two-hectare threshold.
the basis of FR observed at year $t$ and 20 years prior ($t - 20$) as:

$$H_{c,t} = 2 + FR_{c,t} + \frac{4}{FR_{c,t-20}}. \quad (1)$$

The logic underlying this calculation is as follows. The household consists of three generations of members that include children, their two parents ($2 + FR_t$), and their grandparents. We assumed that the four grandparents are distributed amongst the number of children they themselves have had 20 years prior, i.e. $FR_{t-20}$ giving rise to the third term.

We then divide the (past or projected) rural population, reported by the UN Population Division by the average household size to obtain the projected number of rural households (we will re-visit this model below when accounting for structural transformation, below).

5.2.2. Average holding size

To calculate the average landholding size, $LH_{c,t}$, we proceed to divide the total amount of arable land in each country by the number of rural households. The model performs fairly well in explaining historical numbers of landholdings: a comparison of the calculated and historically observed number of landholdings from the WCA (figure S1) displays a reasonably high correlation (slope = 0.964, $R^2 = 0.98$, $N = 101$).

5.2.3. The fraction of small plots

We next assume the distribution of landholding sizes to follow an exponential form. The choice of the exponential function was motivated by the form of historical distributions observed in past data of the WCA, especially in Asia (figures S2(A)–(D)).

Given this assumption, we calculate the fraction of landholdings that are smaller than two hectares as:

$$FP_{c,t} = \int_0^2 \lambda e^{-\lambda x} dx = \frac{1}{LH_{c,t}} \quad (2)$$

where the parameter of the distribution is the average landholding size calculated in step 5.2.2.

5.2.4. The share of land cultivated by smallholders

Similarly, we also calculate the fraction of land cultivated by smallholders as:

$$FL_{c,t} = \int_0^{2} x \lambda e^{-\lambda x} dx = \frac{1}{LH_{c,t}} \quad (3)$$

Modeled and observed fractions of small holdings in historical WCA (figure S3) were also found to be reasonably well correlated (slope = 0.86, $R^2 = 0.7$, $N = 102$).

Overall, the model’s performance is seen to be better in SSA and in Asia than in Latin America and the Caribbean (LAC) (figure S3), where holdings are also relatively larger (mean size in LAC is 13 times bigger than the mean plot size in Asia, ten times bigger than the mean plot size in SSA and six times bigger than the mean plot size in Middle East and North Africa (MENA)). This might suggest that agriculture in that region is structurally different than in other areas. Visual inspection of the observed farm size in the supplementary material (figure 2(C)), also suggests that an exponential distribution does not provide an appropriate fit. Moreover, while a threshold of two hectares may be appropriate in SSA and in Asia, it may be less appropriate in LAC. The analysis that follows is therefore focused on Asia and SSA.

5.3. Accounting for the structural transformation of the rural economy

Until now, we have assumed all rural households to be operating a landholding. Withdrawal from agriculture that is accompanied by migration to urban areas is already accounted for in our model since it is based on existing projections of rural and urban populations. However, not all rural residents are engaged in agriculture as their main source of income. Moreover, the structural transformation of the economy that typically accompanies economic development is likely to gradually shift labor from agriculture to other sources of employment, even within rural areas. Accounting for the impacts of structural transformation on smallholder exposure is both important for our projection and challenging because of the paucity of historical data or established projections of trends in non-agricultural rural employment.

We consider two possible, stylized pathways through which rural agricultural employment declines and which have differing impacts on the distribution of landholdings: (A) some members of each household shift to non-agricultural employment even though the household’s land continues to be cultivated by, or under the supervision of some household members; (B) entire households forgo cultivation altogether and leave their land. In scenario A, even though the share of the rural population that depends on agriculture declines, the distribution of landholdings remains unchanged. In scenario B, the mean holding size increases and the distribution of landholding size shifts to the right (see figure S4 for illustration).

Projecting smallholder shares in scenario B requires a projection of the future rate at which rural agricultural employment will decline. Unfortunately, country level data on these indicators is rather sparse. Nevertheless, we use data compiled by the International Labor Organization and the World Development Indicators Database that reports the share of the population that is employed in agriculture out of the total (not only rural) employed...
population, and, for selected countries \((n = 40)\), also reports the share of the employed who reside in rural areas. Dividing the two gives the share of the rural population employed in agriculture. Estimating the temporal trend of this indicator through linear regression results in a statistically marginally insignificant negative trend of 0.934\% \((p = 0.12, n = 40)\). This finding compares well with the decrease of 1\% per year found in the directly observable fraction of agricultural employment in rural India between 2005 and 2010 (Narasimha et al. 2014). To project future rural agricultural employment rates, we first use the average value observed in each region from the most recent data (tables S2 and S3) and extrapolated it forward using the estimated declining trend reported above (for all regions). We then multiply these projected rates by the number of rural households to obtain the number of landholdings and use it to re-calculate the projected distribution of landholdings as above.

5.4. Application to climate change adaptation

We apply the above projections to calculate the future shares of climate change exposure (defined below) that will be borne by smallholders. To do so, we make use of country level data on the projected change in average temperatures for the periods 2020–2040 and 2040–2060, as compared to the 1961–1999 mean, obtained from the Climate Change Knowledge Portal (World Bank 2011). These projections are based on the median results of an ensemble of global circulation models, aggregated to the country level, under IPCC climate change scenario A2 (Intergovernmental Panel on Climate Change 2008).

We define the relative share of climate change exposure to a given warming level \(\Delta T\) that is projected to be borne by a certain population \(p\) as the ratio \(N_p\Delta T/N_{\Delta T}\) where \(N_p\Delta T\) is the number of person-years between 2020 and 2050 in which a person belonging to population \(p\) is exposed to a temperature change greater or equal to \(\Delta T\); and \(N_{\Delta T}\) is the corresponding number for the entire population in the region in question. Person-years are integrated over countries by taking into account the year in each country in which temperature increases are projected to cross the given temperature threshold.

We calculate this indicator for the share of exposure to be borne by smallholders out of total exposure by the rural population and by the general (rural + urban) population. We also make a parallel calculation of the projected share of climate exposure that is based on shares of arable land, rather than population, i.e. we calculate exposure by summing hectare-years rather than person-years. While the population-based indicators are important from a human income and poverty perspective, the land-based indicator is important from a food production perspective.

Data availability statement

No new data were created or analyzed in this study.

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