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Key Points:

- A context-based framework for projecting sustainable challenges for a hinterland province was established
- Shared socioeconomic pathways (SSP) and implementation of a reforestation program were considered in projected food deficit scenarios for 2030
- The population growth, urbanization and ongoing reforestation will create extra demands for food that cannot be met locally

Supporting Information:

Supporting Information may be found in the online version of this article.

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Unraveling Trade-Offs Among Reforestation, Urbanization, and Food Security in the South China Karst Region: How Can a Hinterland Province Achieve SDGs?

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Abstract Whether the world can achieve the United Nations Sustainable Development Goals (SDGs) largely depends on the ability of less-developed areas to cope with multiple socio-economic changes. The challenges that hinterland areas would face during the realization of SDGs has not yet received enough attentions. In this study, a context-based assessment of regional food balances was conducted, considering key challenges related to socio-economic development as well as land use competition under the framework of the shared socioeconomic pathways (SSPs) and the implementation of reforestation. We examined one of the poorest hinterland provinces in China as a case study, projecting its food deficit and exploring the potential threats to and opportunities for SDG realization by 2030, including population growth, urbanization, urban land expansion and reforestation. The projections revealed a crop deficit of 4.9–9.8 million tonnes, corresponding to the food demands of 10.2–20.6 million people. Approximately 76%–81% of this deficit was expected to be caused by increased food demand, rather than reforestation policies. Therefore, for this less-developed area with low agricultural productivity and large groups of vulnerable people, population growth and urbanization are likely to result in demands for food that cannot be met locally. In addition, large-scale reforestation projects, while enhancing a number of key ecosystem services, will increase the local food deficit by promoting the abandonment of cropland. This will result in greater reliance on food imports, with potential impacts on SDG realization in other regions. These findings highlight the need for integrated governance across multiple scales to ensure hinterland sustainability.

Plain Language Summary The challenges related to the realization of the United Nations Sustainable Development Goals (SDGs) for hinterland areas are often masked by the overall prosperity and economic growth at the national scale. However, these areas are often characterized by delicate trade-offs among multiple development goals. In this study, we established a context-based framework to analyze the impacts of the implementation of multiple sustainable development strategies at different levels in hinterland regions. By combining socio-economic development scenarios and reforestation policies, we quantified the impacts of population growth and urbanization on food demand; exploring the impact on local food production in 2030 of land competition between urban expansion, reforestation and agricultural land. The projections revealed a crop deficit of 4.9–9.8 million tonnes, equivalent to the food demands of 10.2–20.6 million people. Considering the current land use policy, the major reason for this crop deficit was an increase in food demand rather than reforestation. Furthermore, enlarging the scope of the Grain for Green Program, in which croplands on slopes steeper than 15° are converted into forests, would worsen the shortage of local food production. These findings highlight the need for integrated governance to ensure hinterland sustainability within the context of both socio-economic development and climate mitigation.

1. Introduction

At the heart of the United Nations' 2030 Agenda for Sustainable Development is the formulation of 17 Sustainable Development Goals (SDGs), which involve social, economic and ecological dimensions. Context-based scientific support for policymaking has been identified as critical in order to realize the SDGs (UN, 2015a; UN, 2015b; World Resources Institute, 2019). With less than a decade remaining, there is still an urgent need

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to tackle complex interactions across SDGs in order to reinforce particular actions (UNDP, 2016). Despite the SDG's fundamental philosophy of "no one left behind," less developed areas located within rapidly developing countries have often been ignored as they are hidden by the overall prosperity and national economic growth (Conway & Toenniessen, 2013; Omisore et al., 2018; Roche et al., 2017). This threatens the feasibility of achieving SDGs in these regions (Yonehara et al., 2017). Meanwhile, delicate trade-offs in the achievement of multiple SDGs are the result of complex links among SDGs and competing interests across various scales (Fuso Nerini et al., 2018; Nilsson et al., 2016).

To maximize synergies in three dimensions (i.e., economic, social and environmental SDGs), decision-makers need to understand the integrated effects of policies on stakeholders at different levels (Patel et al., 2017; Xu et al., 2020). This seems to be of particularly great significance in hinterland regions of rapidly developing countries because of the associated imbalanced development rates at the national versus regional scale. Hence, trade-offs across multiple SDGs among different levels are likely to become a critical issue when combating inequality and enhancing overall development (Rittel & Webber, 1973).

In less-developed areas, a first focus should be on achieving SDGs related to basic human needs. SDG2 (zero hunger) is one of these needs, and the degree to which SDG2 is achieved will influence the effects of the implementation of other SDGs. When ending hunger is the target, great challenges are faced as future changes in socio-economic and environmental conditions would cause decreased food production and increased food demand (Figure 1). A dynamic approach to monitor progress and guide actions according to the underlying challenges is essential (Costanza et al., 2016).

Food demand has been increasing as a result of population growth and shifts toward meat-rich diets concurrent with the loss of cropland to urbanization, which are related to SDG1 (no poverty), SDG2 (zero hunger), SDG8 (decent work and economic growth), SDG10 (reduced inequalities), and SDG11 (sustainable cities and communities) (Godfray et al., 2018; Tilman & Clark, 2014). However, current agricultural land competition poses great challenges in meeting the associated food requirement. On one hand, the impacts of future urban sprawl on cropland are widespread across rapidly developing regions (d'Amour et al., 2017). On the other hand, to combat climate change and environmental degradation caused by extensive exploitation of nature, large-scale reforestation programs have been launched in order to restore natural vegetation (e.g., trees, grasses) on degraded agricultural land, which is closely linked to SDG13 (climate actions) and SDG15 (life on land) (FAO, 2016; Menz et al., 2013). Food productivity on these croplands is often fairly low, therefore, the agricultural land is a target for environmental change mitigation (such as reforestation) that is an urgent priority from the perspective of global and national sustainability. Nevertheless, for local poverty smallholders in hinterlands, their immediate demand is food rather than environmental change. Therefore, if food demand cannot be met locally, it is very likely that croplands, abandoned in response to environmental policy, will be cultivated again. The long-term perspectives of the associated carbon sequestration are challenged (Chen et al., 2015; Tong et al., 2020). Therefore, projecting the potential food security risks in hinterlands is closely related to the realization of SDGs at national and global levels. This has not yet been well investigated or understood.

To address this knowledge gap, we developed a context-based framework to project the potential challenges with regard to the achievement of SDGs in hinterlands (Figure 1). A typical less-developed mountainous region, that is, Guizhou Province of China, was taken as the study area to illustrate the impacts of population growth (i.e., >36 million residents), urbanization and large-scale reforestation on an increasing food deficit. We employed high resolution state-of-the-art population and urbanization projections under shared socioeconomic pathways (SSPs), and thus combined these with remote-sensing data and census data. Using these data, we estimated food demand and production in Guizhou Province in 2030 under five SSP scenarios and two environmental policy scenarios (Chen, Guo, et al., 2020; Chen, Xia, et al., 2020).

The SSP framework provides predictions about population and economic development in different societal development status and policy options. The framework involves five scenarios that define the range of population growth and urbanization: a sustainable development strategy (SSP1), a middle-of-the-road development pattern (SSP2), regional rivalry and a world of fragmentation scenario (SSP3), an increase in inequality across and within regions (SSP4), and a fossil-fuel development pathway scenario (SSP5) (Fricko et al., 2017; Fujimori et al., 2017; Kriegler et al., 2017; O'Neill et al., 2013; van Vuuren et al., 2017). The two environmental policy scenarios illustrate the different extents of land use policy implementation based on the "Grain for Green Program" (GFGP). GFGP encourages the conversion of sloping cropland into forest land or grassland with compensation to farmers.

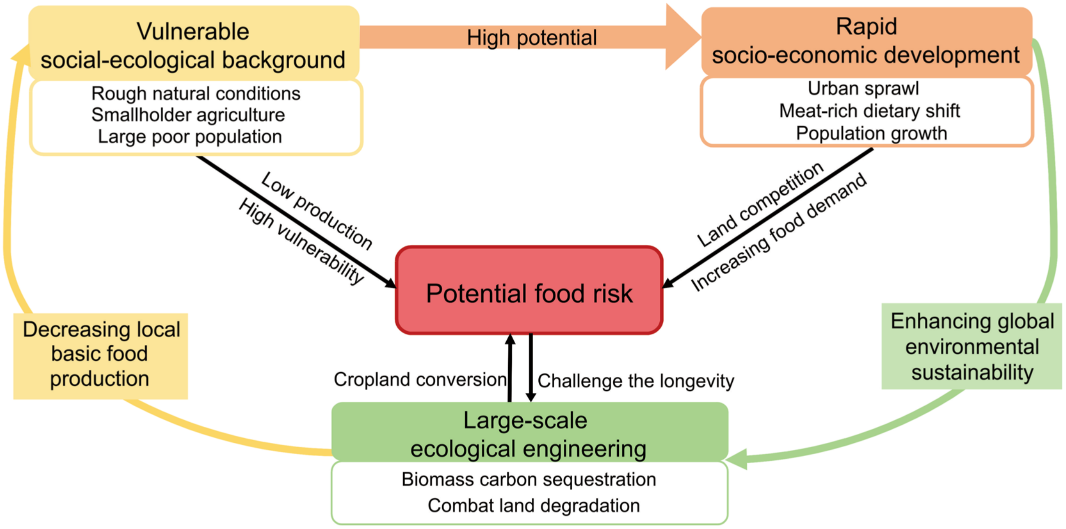

Figure 1. Conceptual framework of food security challenges in a hinterland area.

In the current stage of the GFGP in China, cropland with slopes greater than 25° should be converted. Therefore, we set a "Political Scenario" that is the same as the current policy, which represents the lower limit of the reforestation policy. Another policy scenario, which has not yet been implemented, is considered; this promotes more reforestation and aims to convert cropland on slopes greater than 15° into forest land for better environmental benefits. We simulated such conversions in this study, and call it the "Ecological Scenario." We further investigated different impacts of socio-economic development and environmental policies on the food deficit for the study area and thus illustrated trade-offs between SDGs focused on ending hunger in order to provide evidence-based policy suggestions.

2. Materials and Methods

2.1. Regional Setting

Guizhou Province, with the total land area of 176,000 km^2 and an average elevation of ~1,104 m, is located in the center of the largest continuous karst landscape in Asia, that is, the South China Karst Region. The fragile natural conditions are highly sensitive to human activity due to the presence of shallow soils, low rates of soil formation and rapid transfer of surface water into the bedrock through the irregular surface and permeable nature of the underlying geology (Jiang et al., 2020; Wang et al., 2004) (Figure 2). Furthermore, under population pressure, extensive agriculture activities have been applied on the sloping land, resulting in severe land degradation. The fragmented landscape and less developed social-ecological status have caused low food productivity using extensive traditional small-scale agricultural practices. With more than 90% of the land located in mountains, isolated villages exist with aged and poor population groups. This is one of the least developed areas in China characterized by vulnerable natural-human system.

2.2. Definition of Food

The food production calculated in this study refers to the total amount of five grain crops based on crop statistics data from the National Bureau of Statistics of China. Besides direct crop consumption for food, the consumption from animal feed, the food industry (e.g., used for beer, liquor, and seasoning production), seeding and wastage were also included into the total count. Therefore, grain crops used in this study were sufficient to describe the state of food and nutrition security because major calorie resources are included. In detail, the main crops included cereal (rice, sorghum, millet, and other miscellaneous grains), wheat, corn, beans (such as soybeans), and tubers (potatoes and sweet potatoes; other tubers or roots such as taro and cassava were excluded). In particular, the amount of beans refers to dry beans without pods. The output of tubers was converted into that of grain using a 5:1 ratio. The amount of all the other grains was calculated as husked grain. According to national

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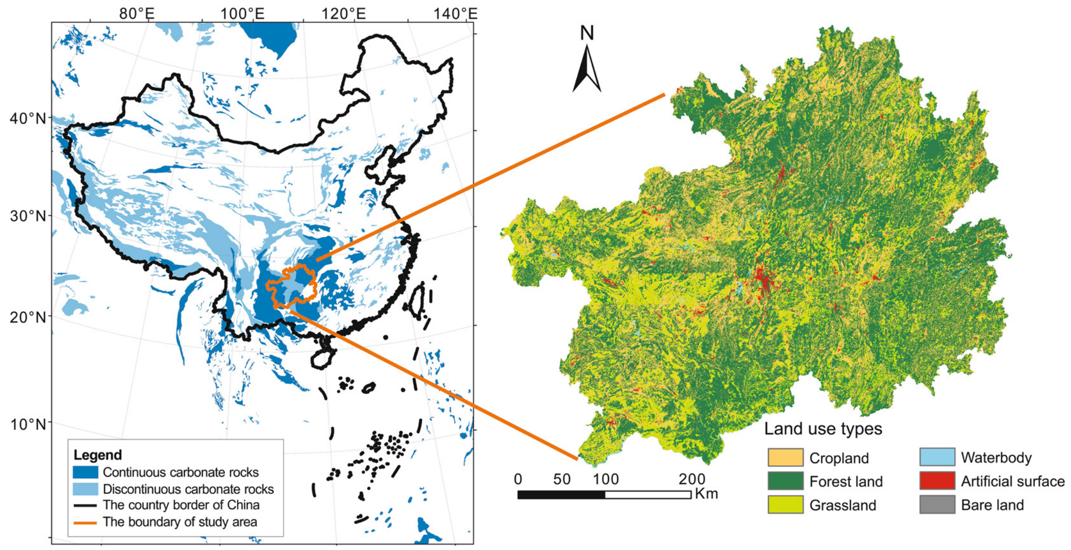

Figure 2. Geographical location and land use pattern of the study area.

standard moisture impurity rates, the production of cereals and beans was calculated as the output of the raw grains after threshing and drying.

2.3. Scenario Design

In this study, we have considered the impacts of socio-economic development and environmental policy on food production and demand in 2030. Regarding socio-economic development, scenarios were set based on the SSPs, which were designed to describe five possible future development trajectories reflecting fundamentally different positions of human societies with respect to the ability to mitigate climate change. The population and urbanization datasets were described in detail in Chen, Guo, et al. (2020). Considering the environmental policy, two types of environmental policy scenarios were designed. Cropland was classified into 5 categories according to terrain characteristics, that is, flat (the slope <2°, 2% of the total cropland); lowly sloping (2–6°, 13%); gently sloping (6–15°, 39%); moderately sloping (15–25°, 30%); and steeply sloping (>25°, 16%). According to the current policies and legal requirement, steeply sloping cropland is to be strictly returned to forest land or grassland. However, as moderately sloping cropland (with slopes between 15° and 25°) has the potential risk of soil erosion, some of these areas will also have been considered for conversion into managed forest land or grassland. The Political Scenario represents the conversion of all steeply sloping cropland into forest land by 2030, which is similar to the current policy approved by the central government in 2015, occupying 16% of the total cropland. The Ecological Scenario delineates a wider range of GFGP targets, that is, to convert all steeply and moderately sloping croplands into forest land or grassland. The baseline scenario describes that food demand and cropland distribution are the same as that in the year 2015.

2.4. Projection of Food Demand

Food demand was estimated by population projections and per capita crop consumption. Previous studies have revealed that urbanization will drive food consumption and dietary shifts to high consumption (Godfray et al., 2018; Tilman & Clark, 2014). According to the positive correlation between food consumption and the urbanization rate, and considering the slowing growth rate of food consumption, we developed a logarithmic function to estimate per capita grain crop demand with the regional urbanization rate as shown in Equation 1:

$$\hat{Y}_i = a\,ln(U_i) + b \tag{1}$$

where U_i is the urbanization rate in year i, a, and b are the estimated fitting coefficients through the least square method using historical data, ln is the Napierian logarithmic function, and $\hat{Y}_i$ is the estimated per capita grain crop demand in the year i.

Therefore, the total grain demand could be calculated as Equation 2:

$$G_i = Y_i \cdot P_i \tag{2}$$

where G_i represents the total grain demand in the year i, and P_i is the total population in year i. The total crop demand data was obtained from the Grain Administration of Guizhou Province and China grain yearbook from 2004 to 2015 (Table S1 in Supporting Information S1). The projected population and urbanization rate data were obtained from the latest population projection data set under SSP scenarios, which provided China's provincial-scale population projections by considering the fertility promoting policies and population ceiling restriction of megacities that have been implemented in China (Chen, Guo, et al., 2020). Additionally, we estimated the affected population through dividing the estimated losses of crop by the annual per capita consumption.

2.5. Estimation of Crop Production and Crop Production Loss

We simulated future crop production and loss caused by urban expansion and GFGP through predicting the future distribution and yield of croplands. Cropland distribution in 2015 was set as the baseline scenario, which was derived from a 30 m resolution land cover data set. The 1 km resolution maps of future global urban land under the SSP framework were also used. The data set preserves spatial details in urban land patterns by combining the Future Land-Use Simulation (FLUS) model, which applies a machine learning approach to capture the complex relationships between urban land expansion and its driving factors. The open-access data set of these projections is available at https://doi.pangaea.de/10.1594/PANGAEA.905890 (Chen, Xia, et al., 2020). By unifying the resolution to 30 m and overlaying the baseline cropland and future urban expansion in 2030, cropland encroached by urban expansion was estimated. Then, through calculating the slope steepness with a 30 m resolution digital elevation model obtained from the geospatial data cloud (http://www.gscloud.cn/), the cropland that would be converted into forest land or grassland in 2030 was determined. Thereby, the cropland distribution in 2030 under five SSP scenarios and two GFGP scenarios were mapped.

Regarding yield, we used the highest yield during 1991–2015 for different slopes to estimate county-level crop production in 2030, considering future crop production improvements in the local limited environmental conditions. In the study area, there are 88 county-level administrative units including municipal districts, counties, county-level cities, autonomous counties, special zones, etc. However, we merged some municipal districts with restricted cropland area and/or production into one administrative unit, resulting in 82 administrative units. The slope of the terrain strongly affects yield by altering soil properties and water conditions in mountainous areas (Ovalles & Collins, 1986), that is, yield decreases with increasing slope (García-Llamas et al., 2019). A field survey demonstrated the relationships between slope and crop productivity in five categories (i.e., cropland with slopes <2°, 2–6°, 6–15°, 15–25°, and >25°) (Feng et al., 2005). Based on this survey, we used the relationship between slope and yield to estimate the annual average yield for five different cropland types in each administrative unit with the following equation:

$$G_{i,j} = \sum_{s=1}^{5} a_{i,j,s} \cdot y_{i,j,s} \tag{3}$$

$$y_{2030,j,s} = \max\left(y_{i,j,s}\right), i \in [1991,\ 2015] \tag{4}$$

where $G_{i,j}$ is the total crop production in the region j for the year i, and $a_{i,j,s}$ and $y_{i,j,s}$ are the area and yield of the cropland types (i.e., <2°, 2–6°, 6–15°, 15–25°, and >25°) in the region j for the year i. Crop production was obtained from Guizhou's statistical yearbook from 1991 to 2015. The historical cropland map (for the years 1990, 1995, 2000, 2005, 2010, and 2015) with 30 m resolution, was derived from Landsat images. For the other years we used the average area of the start and the end of the year, based on the assumption that the trend of cropland change was stable within China's 5-year plan cycle.

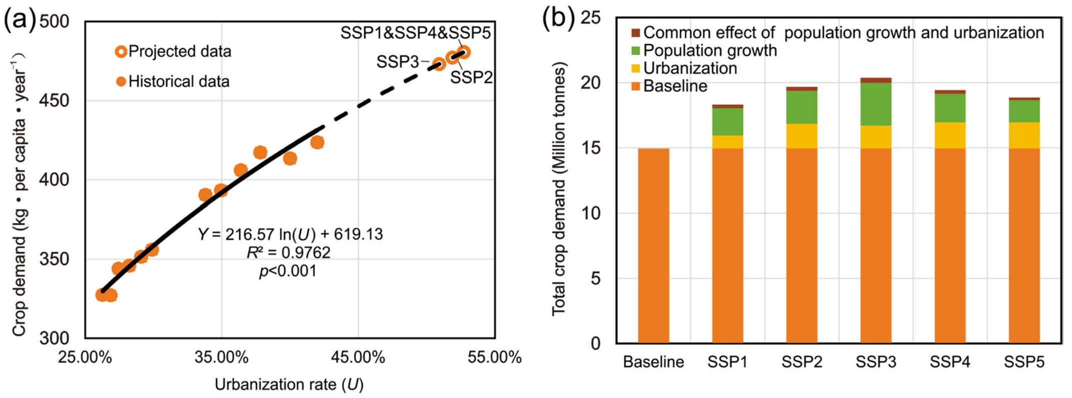

Figure 3. Food demand projections in 2030 with (a) the relationship between urbanization rate and per capital crop demand, and (b) total crop demand under the baseline scenario and five Shared socioeconomic pathways scenarios.

3. Results

3.1. Food Demand

The potential crop requirement in 2030 was calculated to determine whether sufficient food resources would be available to provide adequate nutrition and ensure food security. This calculation took the size of the local population and per capita crop demand growth into account under the five SSP scenarios using the projected total population and urbanization rate in 2030. Based on the hidden linkage between urbanization and per capita crop demand, per capita crop demand under five SSP scenarios were estimated (Figure 3a). The results indicate that per capita crop demand under scenarios SSP1, SSP4, and SSP5 will be 480.51 kg year^{-1} with the same urbanization rate of 52.73% (Table S2 in Supporting Information S1). The estimated per capita crop demand will be 477.08 and 473.01 kg year^{-1} under the scenario SSP2 and SSP3 respectively, corresponding to urbanization rates of 51.90% and 50.93% (Table S2 in Supporting Information S1). In comparison, in the baseline year 2015, it was 423.57 kg year^{-1} and 42.01%, respectively.

For the total crop demand under the five SSP scenarios (Figure 3b), by 2030 a remarkable increase will take place in this region with the range of 26 ~ 36%. Scenario SSP3 reports the highest crop demand, that is, 20.4 million tonnes (Mt), with 3.3 Mt caused by population growth, 1.7 Mt caused by urbanization, and 0.4 Mt caused by the common effect of population growth and urbanization. In contrast, Scenario SSP5 demonstrates the least crop demand at 18.87 Mt. The contributions of population growth, urbanization and their common effect on the increased crop demand under other SSP scenarios are similar with that in SSP3, indicating that given the presence of population growth, the main policy focus should be on addressing crop demands in Guizhou Province.

3.2. Local Food Production

The spatial distribution of cropland in 2030 was simulated under five SSP scenarios and two GFGP scenarios. In the baseline scenario, the area of cropland was 4,874,753 ha. Cropland losses caused by urban expansion are reported under SSP scenarios (Figure S1 and Table S3 in Supporting Information S1), which show that the impact of urban expansion on cropland under the SSP3 scenario will be the smallest, with 1,859.9 ha cropland converted to urban construction land. Scenario SSP5 demonstrates the biggest impact of urban expansion on cropland, with a loss of 2,987.6 ha of cropland. In fact, only less than 0.1% cropland would be lost due to future urban expansion by 2030. When considering the impacts of the GFGP (Table S3 in Supporting Information S1), the results show that under the Political Scenario, cropland loss is approximately 16%, and the cropland will be 4,070,430.5 ~ 4,071,549.9 ha under the five SSP scenarios. In contrast, cropland loss will be much bigger (i.e., over 46%) under the Ecological Scenario.

We calculated the crop productivity of different sloping croplands for each county, and also the crop loss caused by urban expansion and crop production in 2030 (Table S4 in Supporting Information S1). In the baseline scenario, crop production is 15.2 Mt. The crop loss caused by urban expansion is around 5,731–9,3141 tonnes. Under the Political Scenario, the total crop production loss will be around 1.26 Mt, which is about 8% of the

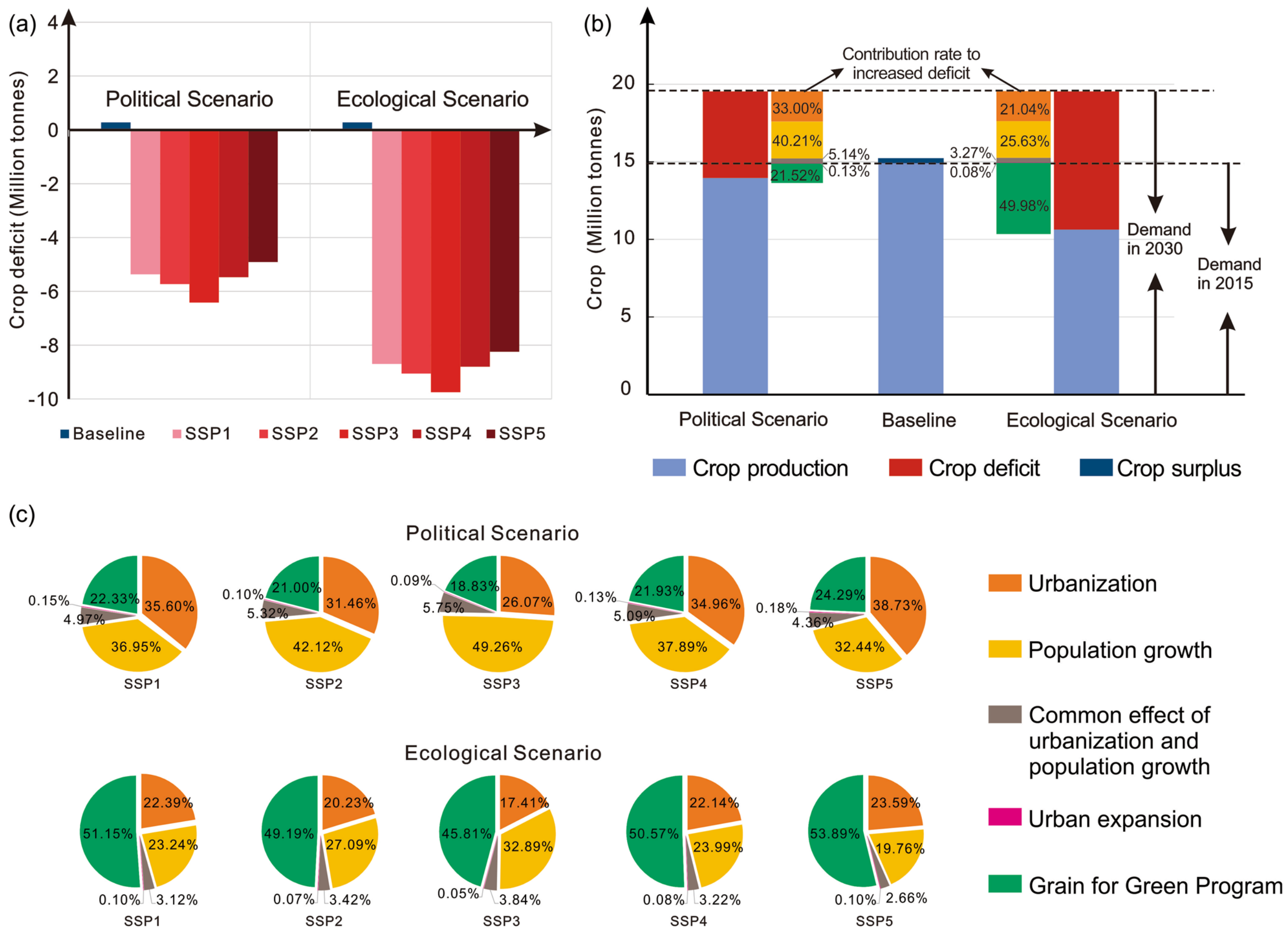

Figure 4. Crop deficit projections by 2030 and associated contributions. (a) Crop deficit (crop production minus crop demand) under baseline, Shared socioeconomic pathways (SSP) and Grain for Green Program (GFGP) scenarios. (b) Population growth, urbanization, urban expansion and GFGP induced increases in crop deficit. (c) Contribution rate of driving factors to crop deficit under five SSP scenarios and two GFGP scenarios.

baseline scenario. Under the Ecological Scenario, the total crop production loss will be about 4.6 Mt, which is a decrease of 30%. Therefore, crop production in 2030 will be 10.6 ~ 14.0 Mt.

3.3. Food Deficit

Under the baseline scenario, there is an estimated crop surplus of 0.25 Mt, indicating that local food demand can be fulfilled by local food production without the impacts of urbanization, population growth and ecological restoration (Table S5 in Supporting Information S1). However, an important crop deficit will occur by 2030 when considering all other scenarios (Figure 4a). Under the Political Scenario, the crop deficit is estimated to be 4.9~6.4 Mt. To illustrate the scale, this is equivalent to almost half of Argentina's total wheat production (11.6 Mt). It is estimated that ~26%–32% of the crop yield required for food cannot be met by local crop production, and consequently, ~10.2–13.6 million local residents will not be able to depend on local crop production. However, under the Ecological Scenario, the food deficit is expected to be even higher (~8.2–9.8 Mt). This means that ~17.2–20.6 million local residents will have to rely on food resources originating from other regions. Hence, in essence, the difference between the Political and Ecological Scenarios in terms of the shortfall in crop provision is ~3.3 Mt. All the results discussed above highlight that local food production is greatly insufficient to meet the growing food demand in the study area.

The contribution rates of all the factors (i.e., population growth, urbanization, urban expansion and GFGP) were investigated in order to determine the most important influencing factors under the different scenarios. The

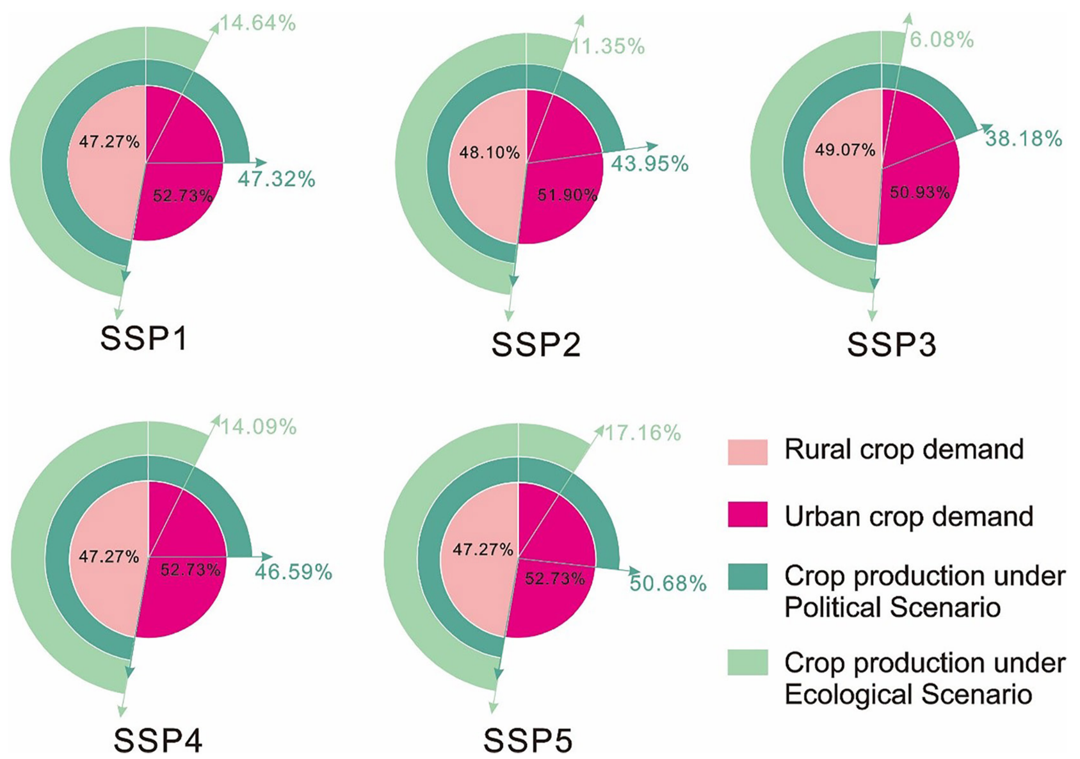

Figure 5. Relationship between crop demand and production in different scenarios. The center circle represents food demand in 2030, composed of the demands from rural and urban residents. The dark green arc represents crop production in the Political Scenario that could balance the total rural crop demand and a higher proportion of urban crop demand. The outside light green arc is crop production in the Ecological Scenario that could balance the total rural crop demand and a lower proportion of urban crop demand.

results show that urban expansion explains the least amount of food deficit under all scenarios, that is, less than 0.2% of contribution rate (Figure 4b). For other factors (Figures 4b and 4c), under the Political Scenario, population growth is expected to become the largest contributing factor (∼32–50%), whilst the contributions of urbanization (∼26–39%) and the GFGP (∼18–25%) are also relatively high. In contrast, under the Ecological Scenario, GFGP becomes the dominant factor contributing for ∼45–54% of the growing crop deficit, whereas population growth and urbanization are ranked the second and third with contribution rates of ∼19–33% and ∼17–24%, respectively. When comparing different SSP scenarios (Figure 4a), food deficit is the highest under SSP3, which is characterized by the greatest population growth and lowest urbanization rate in all five SSP scenarios, though conversion of cropland into urban construction land is very limited. Food demand is the key factor causing different food deficit amounts across the five SSP scenarios, while the difference in food deficit between GFGP scenarios results from food production.

3.4. Urban-Rural Demand Allocation of Crop Production

Amongst the poorest groups, rural residents who live in remote villages and mountainous areas should be given more attention, because a significant proportion of vulnerable people live there, including the elderly and children in poverty who are easily threatened by food price fluctuations. Therefore, aiming to fulfill the rural crop demand through local crop production should be considered as a priority in order to ensure the basic demand of rural residents. This strategy is also relevant to end hunger in those areas where food or nutrient insecurity are most evident. The results show that the rural crop demand could be balanced under all scenarios (Figure 5). Under the Political Scenario, food demand for all rural residents and approximately 38%–51% of urban residents could be met by local crop production, which corresponds to more than 10 million people who would rely on crop production from elsewhere in order to ensure their food security. Under the Ecological Scenario, although food shortage would be exacerbated, local production can still feed rural residents, which means that if there are related policies to give priorities for rural areas, rural communities' food security can be guaranteed.

4. Discussion

4.1. Neglected Hinterland When Monitoring National Progress of SDGs

Our results reveal the huge food deficit that will arise from social-ecological development in the hinterland, particularly as socio-economic development is expected to be the major hurdle for achieving food security over the next decades, which means that local food production is not able to follow the increase in food demand as a consequence of urbanization and population growth.

The fact that urbanization could increase food consumption in developing countries has been reported in previous studies. With the development of urbanization, people shift their diets toward animal-based food sources (Godfray et al., 2018; Springmann et al., 2018). This enlarges human demand on crop production, because it takes 3–8 kg of grain to produce 1 kg of meat. A study predicted that almost 40% more land would be needed by 2030 to feed the increasingly affluent urban population for the whole of China (Gu et al., 2019). Similarly, in this study, the contribution rate of urbanization to food deficit is expected to be ∼26–39% under the Political Scenario, implying relatively high pressure from urbanization on future food security.

Population growth also plays an important role in the future food deficit, especially under the Political Scenario, highlighted by ∼42% contribution rate to the crop deficit. Food deficit under SSP3, a regional rivalry scenario, is the most remarkable because of rapid population growth. More importantly, under this development pathway, the competitiveness among countries will result in more dependence on local food production, increasing the need to reclaim forested areas for agricultural activities. Nevertheless, according to the current trend in population growth, SSP5 illustrates a more realistic and lowest population level for 2030 (i.e., less than 40 million), and therefore the smallest crop demand (i.e., ∼18.9 Mt). Under this scenario, migration between provinces will be common because of high investment in education and an active capital market, though this scenario relies on the intensive use of fossil-fuels and so also poses severe challenges for climate change mitigation.

With the development of food marketing and convenient transportation, the standard for measuring food security goes beyond the consideration of closing the borders to feed local people with local food, since there is an established global and national food trading system (Godfray et al., 2010; Hu et al., 2020). However, the widespread hinterland regions with inadequate food production and large groups at risk of poverty are fairly isolated from markets, resulting in higher vulnerability to emergencies; as seen when the importing network was interrupted during the COVID-19 pandemic (Nordling, 2020). Evaluating food deficits based on specific contexts at the local scale for such areas becomes critical in order to ensure individual welfare and to achieve the goal of zero hunger. The predicted food deficit in Guizhou Province provides an example for other hinterland places, for which a potential food crisis in the era of changes in policies and emergencies has not yet been well studied.

4.2. Land Competition Between Reforestation and Food Production

To combat climate change and land degradation, large-scale reforestation has been implemented in southwestern China, with this area presenting one of the most significant increases in greenness and carbon sequestration globally (Brandt et al., 2018). Converting cropland on sloping hills and degraded land to forest land is the most universal approach to sequester carbon in biomass (Tong et al., 2018). Nevertheless, land competition between food production and reforestation threatens the long-term continuity of this particular carbon sink (Chen et al., 2015; Lu et al., 2015). Our results suggest that the current GFGP implementation in Guizhou Province will not adversely affect local food security by 2030 because of the low productivity of the sloping cropland (i.e., ∼16% cropland conversion causing a net loss of crop production of ∼8%). As a result, the large amount of fertilizer input could be reduced, such as N fertilizer that was previously added to low-yielding sloping cropland. Therefore, despite the loss of food production, other important sustainability gains can be made through the GFGP, such as greenhouse gas emissions reductions, water pollution mitigation, soil retention, and carbon sequestration (Bryan et al., 2018; Tong et al., 2020). Focusing efforts on increasing yield in more productive areas may allow overall food production to be maintained or enhanced while reducing environmental pollution.

When expanding the range of cropland conversion from considering all slopes steeper than 25° to include those steeper than 15°, as simulated in the Ecological Scenario, GFGP becomes the main factor explaining the local crop deficit with the contribution rate of ∼45–54%, and therefore will dominate the long-term food insecurity of the region. Because residents who live in remote mountainous villages often lack financial capital, exploitation

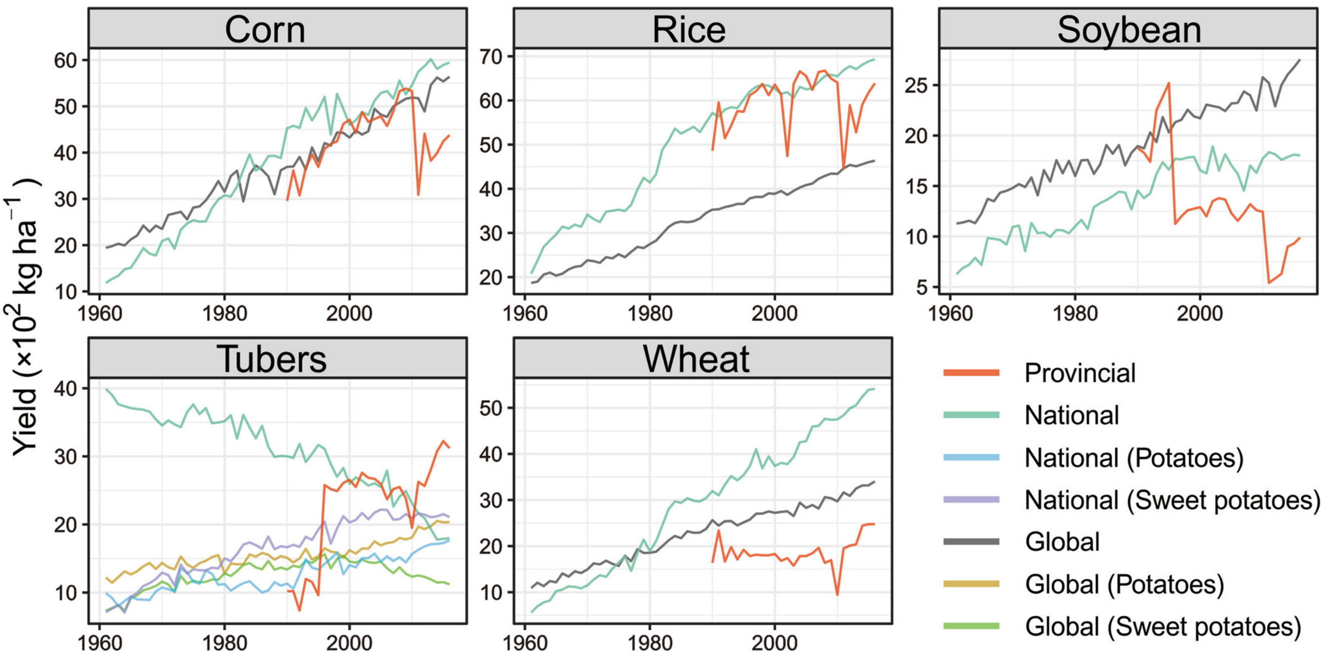

Figure 6. Average yield change trends of five main crops during 1960–2016 for the global and national level and during 1990–2016 for the provincial level.

of existing forests to grow crops may occur again once local food needs cannot be satisfied (Wang et al., 2004). The traditional agriculture and diet culture also influence land use. Under these circumstances, ensuring reliable food resources from local production is likely to have priority over environmental restoration efforts in order to sustain local farmers' livelihoods (Wang et al., 2019). In addition, due to the complex international situation and emergencies, in recent years, the Chinese government has paid more attention to ensuring food security. For example, stimulating the cultivation of basic cropland for food production, rather than economic fruit or trees. This policy has caused difficulties for the implementation of GFGP in some areas characterized by limited arable land area, such as Guizhou Province. Hence, basic human demands should be considered as key elements at any level of decision-making when considering the complex trade-offs among various SDGs across multiple scales. As such, systematic solutions are urgently required.

4.3. Potential Strategies Addressing the Challenges

Closing the yield gap is one of the most effective ways to deal with regional crop deficit (Cole et al., 2018). Here we discuss potential strategies to increase crop yields (Figure S2 in Supporting Information S1). Under the Political Scenario, to feed local people with local crop production by 2030, ~4.1 million ha of cropland would be needed to produce ~18.9–20.4 Mt of crops, and hence the crop yields should reach ~46,357–50,046 hg/ha by 2030. Based on the highest average yield of cropland when slopes greater than 25° are converted (~34,288 hg/ha), the yield needs to additionally increase by ~35–46%, which is difficult to reach.

Compared to the national and global average yield of the five main grain crops (Figure 6), corn and rice (which occupy most croplands across the province) were characterized by lower yields than national average levels, though with an increasing trend. However, tubers (such as potatoes and sweet potatoes) exceeded the average yield at the national level. Furthermore, low yields were also typical for wheat and soybean (i.e., slightly more than 50% of the national level), but these grain crops were not widely planted across Guizhou Province, occupying only 12% of the grain cropland area. Although an overall increasing trend in crop yield is expected in the future (Figure 6), the GFGP will reduce the total cropland area. These lost croplands are characterized by a much lower yield than the regional average, which means that the average yield after GFGP implementation will also increase as a result of abandoning low productivity cropland.

There are also other challenges to improving local food productivity within less developed hinterlands across the world. For this fragmented landscapes, the required machinery and large-scale agriculture are hard to implement, and investigations into new technologies in planting, fertilizing, irrigation or drainage, as well as pest or weed control for such heterogeneous landscapes are still rare. Small-scale farmers who lack other economic opportunities and rely on high-input but low efficiency agriculture systems are widespread. Introducing optimal management for those farmers will be a daunting but very important task. The current government provides financial payments for land conversion, as well as grain subsidies to protect local farmers' livelihoods (Delang & Yuan, 2015). In addition, sustainable agricultural management and technology should be preferable for the wider region.

The reforestation programs combined with the specific karst landscape can attract tourists; and tourism will further help rural communities to transform toward more off-farm oriented livelihoods and increase the household income. In this way, multiple SDGs can be addressed because the rural residents can join the market chains to obtain food instead of cultivating less productive land. The aim of this study is not to encourage the production of local food to feed residents' demand, however, it is critical for the provincial government to acknowledge the potential huge food deficit raised by the projection of urbanization and reforestation, and make corresponding policies to prevent large-scale food crises. This projection is also meaningful for economic and industry development plans. As such, the challenges to achieving SDGs for hinterlands can be identified in an efficient way with potential solutions investigated and explored in advance.

4.4. Validation and Uncertainties

The first source of uncertainty in this study is the projection of per capita food demand according to the urbanization rate. We used national data to make a validation. It was reported that by 2019, the share of grain per capita in China reached 470 kg year^{-1} (China State Council, 2019). For Guizhou Province in 2019, the urbanization rate was ∼49%, and thus, using the projection model, the share of grain per capita in Guizhou Province should be around 465 kg year^{-1}, which was slightly lower than the national average. This is reasonable because socio-economic development in Guizhou Province is lower than the national average level. This validation procedure implies that the estimation of per capita food demand is reliable. Due to uncertainties related to the population projection data set, the total amount of food demand and food deficit might be over-estimated. In the future, the food deficit could be projected with an updated data set for population projection considering population migration across the country. In addition, we considered crop productivity differences across different slopes, however, uncertainties in the present study are mainly because of the lack of spatial crop yield datasets. The crop productivity data at the county level is a little coarse to distinguish the yields of different slopes, since distinct heterogeneity exists in the karst mountainous region. Also, water and soil conservation measures have not been considered when estimating crop yield; terrace planting has been applied in the study area, which could improve the crop productivity of sloping cropland. This action will be expanded in the future, which could further improve crop productivity and thus, GFGP induced losses of crop productivity could be underestimated.

5. Conclusions

Attention should be given to hinterland regions as they move toward the realization of SDGs in 2030, in order to understand how implementing socio-economic development would affect local basic needs. Here, we employed a detailed case study of one of the poorest areas located within the mountainous region of China to illustrate the concrete challenges through scenario projections of food deficit under the framework of the SSPs and vast ongoing reforestation projects. The projections reveal a crop deficit of ∼4.9–9.8 Mt by 2030 in the context of increasing population, urbanization and the GFGP (corresponding to food demands for ∼10.2–20.6 million people). Approximately 76%–81% of the crop deficit is expected to be due to increased food demand under the current sustainable land management scenario. Furthermore, if ecological restoration projects expand, there is a substantial increase in pressure on food production and ∼46–54% of the food deficit can be attributed to land loss to reforestation.

This study implies that for the less-developed remote areas with low agricultural productivity and a large proportion of vulnerable population groups, population growth and urbanization are likely to create extra demands for food that cannot be met locally. In this context, the large-scale ongoing reforestation projects will worsen this issue by promoting the abandonment of cropland. However, because the abandoned cropland is of low productivity, the mitigation actions within the current context of reforestation may have a relatively smaller contribution to the total food security issue, and more importantly, there are likely other benefits such as climate change mitigation. For poverty alleviation, a key priority should be ensuring that the rural food demand is met, and that crop yield in high productive areas can be maximized. Nevertheless, the increasing food demand in urban areas cannot be met within the region and would likely result in greater reliance on imports. This will in turn have potential impacts on food security and associated SDGs of other regions through global or national food trading system.

Conflict of Interest

The authors declare no conflicts of interest relevant to this study.

Data Availability Statement

Population and urbanization rate projections under SSP scenarios in 2030 for China are available at https://doi.org/10.6084/m9.figshare.c.4605713.v1. The maps of future global urban land under the SSP framework are available at http://www.geosimulation.cn/GlobalSSPsUrbanProduct.html. The digital elevation model is available at http://www.gscloud.cn/. Requests for further information and resources should be directed to the corresponding author.

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