Assessing Climate and Transition Risks to China's Agriculture under 1.5°C and 2.0°C Global Warming Scenarios

Tao Gan,Wei Xie, Tariq Ali, Qinyu Deng, Qiang Ji

Abstract: China's agriculture faces dual risks from climate change and the transition to low-carbon agriculture, which has not been adequately studied in the literature. This study fills this research gap by assessing climate and transition risks under the 1.5°C and 2°C scenarios. Through meta-analysis, we derived loss functions for climate change impacts on China's staple crops and then used temperature projections to estimate yield losses across various scenarios. Our results indicate that yield losses are highest in the absence of climate action and that losses under the 2°C scenario exceed those under the 1.5°C scenario. Furthermore, examining three key transition policies to low-carbon agriculture—rising costs of agricultural greenhouse gas reductions, occupation of arable land for solar energy infrastructure, and increased bioenergy-driven food demand—reveals potential risks to food security. Using an economic (GTAP-E) model, we compared climate and transition risks and found that under the 2°C scenario, less ambitious climate targets lead to lower transition risks but higher climate risks. In contrast, under the 1.5°C scenario, more ambitious climate targets result in higher transition risks but lower climate risks. Overall, the aggregate risk in the 2°C scenario was lower than that in the 1.5°C scenario. These findings highlight the need for policymakers to comprehensively evaluate these risks to ensure food security during a low-carbon transition.

Keywords: Agricultural Low-Carbon Transition; Climate Risks; Transition Risks; Loss Function.

1. Introduction

Agricultural systems play a crucial role in global greenhouse gas (GHG) emissions (Hu et al., 2023), accounting for about 34% of total global emissions (Crippa et al., 2021). The main sources include enteric fermentation of livestock (Havlík et al., 2014) and chemical fertilizers (Gao & Cabrera Serrenho, 2023). According to *The Third Biennial Update Report on Climate Change of the People's Republic of China* (2023), agricultural activities contribute 6.7% of the country's total greenhouse gas (GHG) emissions and 35.7% of non-CO_2 GHG emissions. Agricultural production contributes 37.2% and 49.2% of national methane and nitrous oxide emissions, respectively. Agriculture and food systems have emerged as key priorities in global climate governance at COP28. More than 130 countries have signed *the COP28 UAE Declaration on Sustainable Agriculture, Resilient Food Systems, and Climate Action*, which explicitly requires countries to integrate low-carbon transitions in agriculture and food systems into their mitigation strategies. The declaration emphasizes the reduction of greenhouse gas emissions in agriculture through technological innovation and financial support. This international consensus not only underlines the crucial role of agriculture in climate governance but also offers significant opportunities to drive the low-carbon transitions in agriculture.

However, the particularity of agriculture makes its low-carbon transition particularly vulnerable to multiple risks. On the one hand, agriculture is one of the sectors most affected by climate change (Chen & Gong, 2021). Rising temperatures, changing precipitation, and extreme climate events directly threaten crop yields (Zhao et al., 2016; Ben Mariem et al., 2021). Moreover, the negative impacts of climate change on agriculture are accelerating. Over the past 50 years, the adverse effects of heatwaves and droughts on European crop yields have doubled, increasing from 2.2% during 1964-1990 to 7.3% during 1991-2015 (Brás et al., 2021). Climate-induced changes in agricultural production and trade patterns could potentially threaten food security (Li et al., 2022). However, climate policies are likely to introduce a series of transition risks to the agricultural sector (Hasegawa et al., 2015). For example, increasing demand for bioenergy and renewable energy infrastructure, such as wind and solar power, will likely further reduce the availability of arable land for food production (Hasegawa et al., 2020). Moreover, the large investment and technological change in agricultural carbon mitigation may sharply increase the cost of production, which could lead to an increase in food prices and a corresponding decline in food consumption (Fujimori et al., 2022). Balancing climate goals with transition risks and exploring low-carbon transition pathways suitable for China's agriculture have become urgent challenges that need to be addressed to ensure food security. However, current research lacks comparative studies on the climate and transition risks in China's agriculture are lacking. In particular, the assessment of transition risks in the low-carbon agricultural transition process remains insufficient. Not knowing whether climate or transition risks in agriculture are more severe partly hinders the advancement of measures to reduce greenhouse gas emissions. This study aims to fill the research gap by systematically assessing the climate and transition risks to China's agricultural sector under 1.5°C and 2°C scenarios. We design six different scenarios: a baseline scenario (NCC), a no-policy-impact scenario (NP), and four scenarios that include or exclude residual climate impacts under the 1.5°C and 2°C scenarios. These different scenarios allow us to assess the combined effects of climate change and transition policies, which will produce different levels of risk for China's agriculture. To achieve this, the paper first employs a meta-analysis approach, and summarize the results of over 400 studies that utilize three primary research methods: warming experiments, local process models, and statistical models. From these studies, we derive loss functions to assess the impacts of climate change on three major staple crops in China—maize, rice, and wheat. This analysis helps to identify the climate risks faced by China's agricultural sector. Next, we use the GTAP-E model to assess how solar energy projects, bioenergy expansion, and agricultural GHG mitigation strategies affect agricultural production, prices, consumption, and self-sufficiency. Through this, we aim to uncover potential transition risks within the sector. Finally, we compare climate and transition risks across different scenarios and propose sustainable mitigation pathways to minimize risks for China's agriculture.

2. Risks of transition to low carbon agriculture

As shown in Fig.1, agriculture faces two categories of risks under different climate target transition pathways: climate and transition risks (Gambhir et al., 2022). Limited climate mitigation measures will cause substantial climate risks to agriculture owing to the intensification of climate change (Rosenzweig et al., 2014). In contrast, pursuing stricter climate targets necessitates the adoption of more stringent climate policies, which could impose increased transition risks on agriculture (Kaufman et al., 2020).

The impacts of climate change on agriculture can be categorized into two types: gradual, long-term, and abrupt effects caused by extreme weather events. Long-term effects mainly include rising temperatures and changing precipitation patterns, which negatively influence agricultural productivity (Iizumi et al., 2017). These effects can be mitigated by adaptation strategies, such as enhancing germplasm research, optimizing crop varieties, and adjusting sowing schedules (Challinor et al., 2014). In contrast, the abrupt effects of extreme weather events, such as droughts, heat waves, and heavy precipitation, often occur suddenly and have a more severe negative impact on agricultural output. These events can result in widespread yield reductions or complete crop failure, posing a significant challenge to the stability of agricultural production.

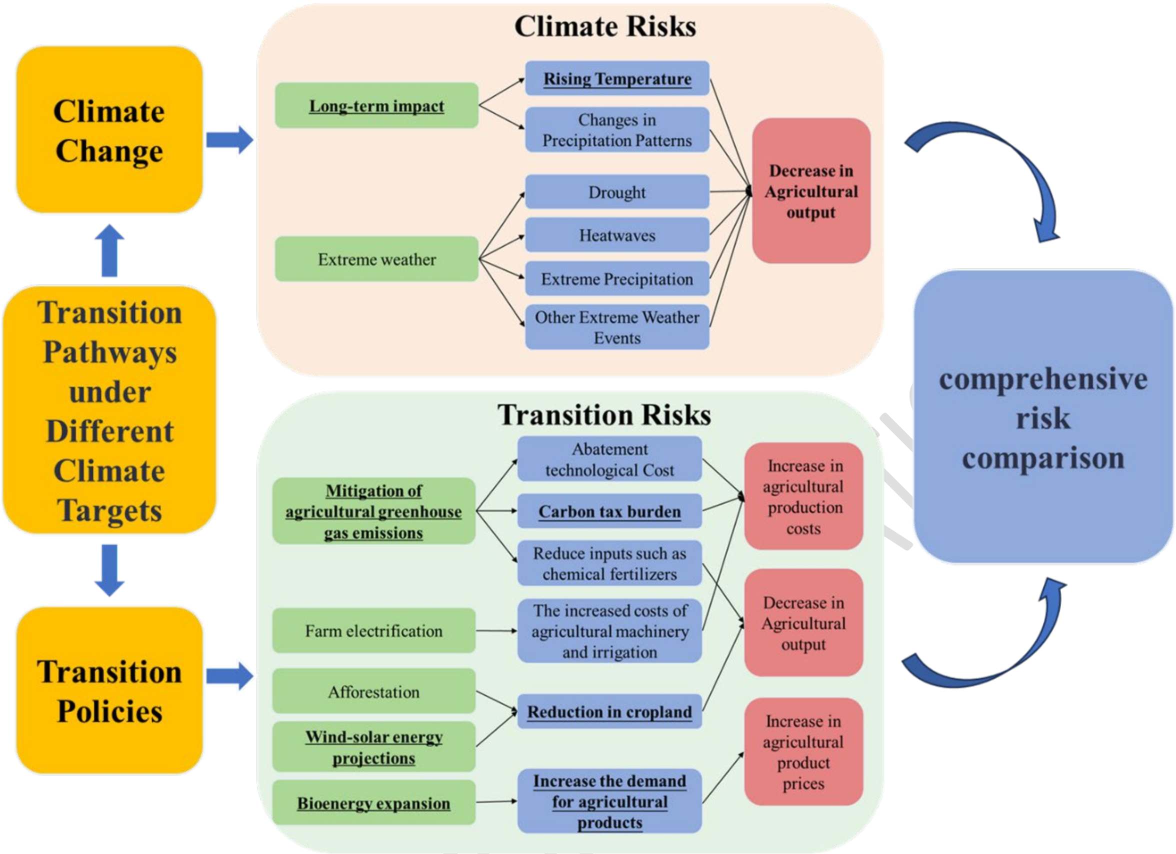

Figure 1. Climate risks and transition risks mechanisms of agriculture under different transition pathways. The underlined part highlights the mechanisms of climate risks and transition risks examined in this paper.

The transition risk from agriculture mainly includes: (1) mitigation of agricultural greenhouse gas emissions. These policies require a deep revolution in current agricultural production, and relevant management and technology investments may increase costs and affect farmers' incomes in the short term (M. Chen et al., 2022; Wang et al., 2022). For example, reducing methane (CH_4) emissions requires precise paddy field management, optimized livestock feeding practices, and enhanced manure management (Ding et al., 2024; Darikandeh et al., 2025). Reducing nitrogen oxide (N_2O) emissions requires no-tilling farming, crop rotation systems, promotion of nitrogen fixation technologies for legumes, and reduction of nitrogen fertilizers and pesticides (Aluko et al., 2023). Additionally, incorporating agricultural greenhouse gas emissions into the carbon trading market may increase the cost of agricultural production through a unified carbon price and carbon tax mechanism; Kazimierczuk et al., 2023; Phelan et al., 2024). (2) Agricultural electrification; the rollout of electric machinery and renewable energy is important for the decarbonization of agriculture, but the initial investment and maintenance costs may be financially burdensome in areas where electrification is not yet widely available (Farokhi Soofi et al., 2022). Transition risks from other sections mainly include: (1) forest carbon sequestration policies and large-scale afforestation programs, which may reduce the availability of arable land, thereby affecting agricultural production capacity and threatening food security (Doelman et al.,2018; Fujimori et al., 2022). (2) Large-scale wind and solar energy projects often occupy farmland, leading to higher land rent and agricultural production costs (Zhang et al., 2023). (3) The expanding demand for bioenergy, which can compete with food crops for limited arable land, exacerbates the shortages of land required for food production; Hasegawa et al., 2020).

Under different transition pathways, climate and transition risks reflect trade-offs between the benefits and costs of implementing climate policies in the agricultural sector. Stricter climate policies can significantly mitigate climate risks but may increase transition risks, whereas more lenient policies reduce transition risks but result in greater climate risks. Therefore, we can only identify the most suitable pathway for China's agricultural transition by comprehensively comparing the combinations of these two types of risks across different transition pathways and conducting cost-benefit analyses. Owing to limitations in available data, modeling techniques, and research methodologies, this study primarily focuses on the long-term warming effects of climate change on major staple crops. In addition, it emphasizes the transition risks associated with agricultural greenhouse gas emission reductions, occupation of farmland by photovoltaic installations, and expansion of bioenergy production. By analyzing these key mechanisms, this study compares the climate and transition risks of agriculture with different climate targets.

3. Methods

The paper used a meta-analysis to derive the climate change impacts on China's maize, wheat, and rice, and the GTAP-E model to simulate the impacts of both climate change and low-carbon transition policies.

3.1 Meta-analysis

Literature review. In this study, the loss functions for climate change impacts on China's three staple crops, maize, wheat, and rice, were developed using a meta-analysis approach. Literature selection was conducted using a keyword search method with the following inclusion criteria: (1) the focus of the study must be on the three staple crops—maize, wheat, and rice; (2) the study regions must include China; (3) the results must include projections of future climate change impacts, rather than being limited to historical effects; and (4) the study must employ quantitative rather than qualitative analysis. A total of 3,780 articles were retrieved from various databases, of which 52 met the inclusion criteria and encompassed 409 data points. These studies primarily focused on three mainstream research methods: Warming Experiments, Local Process Models, and Statistical Models (Zhao, Piao, Huang et al., 2016). Additionally, we distinguish whether the CO_2 fertilization effect is considered with the aim of exploring the potential impact of rising atmospheric CO_2 concentrations on agricultural yields during climate warming. Two methodologies were applied to analyze the meta-results: bootstrap resampling and meta-regression analysis.

The bootstrap resampling method. For each data point i, we can extract the temperature increases (ΔT_i) and corresponding percentage yield changes ($\Delta Y_{crop,i}$) from the literature. The yield loss per degree Celsius increase in temperature for each sample point was calculated as follows:

$$D_{crop,i} = \Delta Y_{crop,i} / \Delta T_i$$

According to the bootstrap resampling procedure, a set of resampled $D_{crop,i}$ values was generated, and the mean of these resampled values was computed. Repeating this process 1,000 times generates an empirical bootstrap distribution for the mean of the resampled values. Then, we can compute both the average effect of temperature on crop yield and the heterogeneity among individual samples. Taking D^*_{crop} represents the mean of the empirical bootstrap distribution. Under the assumption that the area remains unchanged, we can use the grid-scale crop output and temperature changes to estimate the aggregated yield change for each crop under various scenarios.

$$Yield\_Change_c = (\sum_{g=1}^{n} output_{c,g} \times \beta_c^* \times \Delta T_g) / \sum_{g=1}^{n} output_{c,g}$$

Specifically, $Output_{c,g}$ represents the total output of each crop in each grid cell, ΔT_g denotes the average temperature change for each grid cell, $Yield\_Change_c$ indicates the aggregated yield change for each crop.

The meta-regression method. To further account for the heterogeneity in CO_2 fertilization effects, publication year, and study region, this study employed a meta-regression approach to quantify the response of crop yield percentage changes to temperature variations. The regression equation applied is as follows:

$$\Delta Y_{crop,i} = \alpha + \beta \Delta T_{crop,i} + i.Year_{crop,i} + i.Region_{crop,i} + \varepsilon_{crop,i}$$

Here, $Year_{crop,i}$ and $Region_{crop,i}$ are dummy variables that represent the publication year and study region, respectively. Coefficient β represents the percentage change in crop yield per 1°C increase in temperature. Furthermore, by performing bootstrap resampling on the sample points and conducting regression analysis on each resampled dataset, the resulting β coefficients construct a probability distribution. This distribution also reflects the average effect of temperature on crop yield and the associated uncertainty. Let β_c^* represent the median probability distribution for each crop. Assuming that the area remains unchanged, we can compute the aggregated yield change for each crop under various scenarios.

$$Yield\_Change_c = (\sum_{g=1}^{n} output_{c,g} \times \beta_c^* \times \Delta T_g) / \sum_{g=1}^{n} output_{c,g}$$

Specifically, $output_{c,g}$ represents the output of each crop in each grid cell; ΔT_g denotes the average temperature change for each grid cell; $Yield\_Change_c$ indicates the aggregated yield change for each crop.

3.2 GTAP-E model

The GTAP-E model is an extension of the standard GTAP model, which incorporates energy as a production factor into the production structure and integrates carbon tax variables and carbon emissions trading mechanisms (see Truong, 2007 for details). To analyze the impact of climate change on supply and demand in the agricultural sector, we aggregated the non-agricultural sectors in the GTAP database (version 11, base year 2017) into seven broader categories while retaining 13 agricultural sectors. Because the GTAP database does not have a separate sector for maize, we use the coarse grain sector, excluding rice and wheat, as the maize sector (maize accounts for up to 95% of this sector for China).

We simulated the crop yield impacts of climate change on maize, rice, and wheat in China by adjusting the regional land-use efficiency. This approach effectively translates climate shocks directly into crop yield loss. To assess the impacts of transition policies, this study employs the following approaches: (1) simulating the occupation of arable land by photovoltaic installations through a reduction in land resources; (2) modeling the expansion of bioenergy demand by increasing the agricultural sector's supply to the bioenergy sector (e.g., ethanol production et al); and (3) simulating the effects of agricultural greenhouse gas mitigation policies by imposing a carbon tax on the agricultural sector under agricultural carbon reduction targets.

3.3 Scenarios settings

Table 1:Scenario Settings

Scenarios	Description
NCC	No climate change and mitigation measures

NP	Only climate change impacts under RCP8.5
1.5°C*	Mitigation measures for 1.5°C stabilization without residual climate change impacts
1.5°C	Mitigation measures for 1.5°C stabilization + Residual climate change impacts
2°C*	Mitigation measures for 2°C stabilization without residual climate change impacts
2°C	Mitigation measures for 2°C stabilization + Residual climate change impacts

To comprehensively assess the climate and transition risks faced by China's agriculture under the 1.5°C and 2°C scenarios, we defined six scenarios: the baseline scenario (NCC), no-policy scenario (NP), and 1.5°C and 2°C scenarios, both with and without residual climate impacts (Hasegawa et al., 2018). The baseline scenario assumed no climate change and maintained current policies without additional climate action. The no-policy scenario assumes the same policy as the baseline, maintaining current policies, but it is affected by climate impacts under the RCP8.5. The policy goal for the 1.5°C scenario is to limit global cumulative CO2 emissions to 400 GtCO2, ensuring that the global temperature rise is kept below 1.5°C by the end of the century. The policy goal for the 2°C scenario is to limit global cumulative CO2 emissions to 1000 GtCO2 with the aim of keeping the global temperature rise below 2°C by the end of the century. The climate impact under no climate policies can be evaluated by comparing the no-policy scenario with the baseline scenario. Comparing the 1.5°C and 2°C scenarios without considering climate impacts helps clarify the effects of climate policy, that is, the magnitude of transition risks. Finally, the climate effects under these two scenarios can be revealed by comparing the 1.5°C and 2°C scenarios with and without climate impacts.

4. Result

4.1 Climate change-induced risks to agriculture

4.1.1 The climate change-induced loss functions

We employed meta-regression and bootstrap sampling methods to construct climate change-induced loss functions for maize, rice, and wheat, quantifying the impact of a 1°C temperature increase on the yields of these staple crops. The findings reveal that maize is projected to suffer the most significant yield losses, followed by rice, whereas wheat is comparatively less impacted. Meta-regression analysis showed that for every

1°C increase in temperature, the median yield losses for maize, rice, and wheat were 7.4%, 6.54%, and 0.62%, respectively.

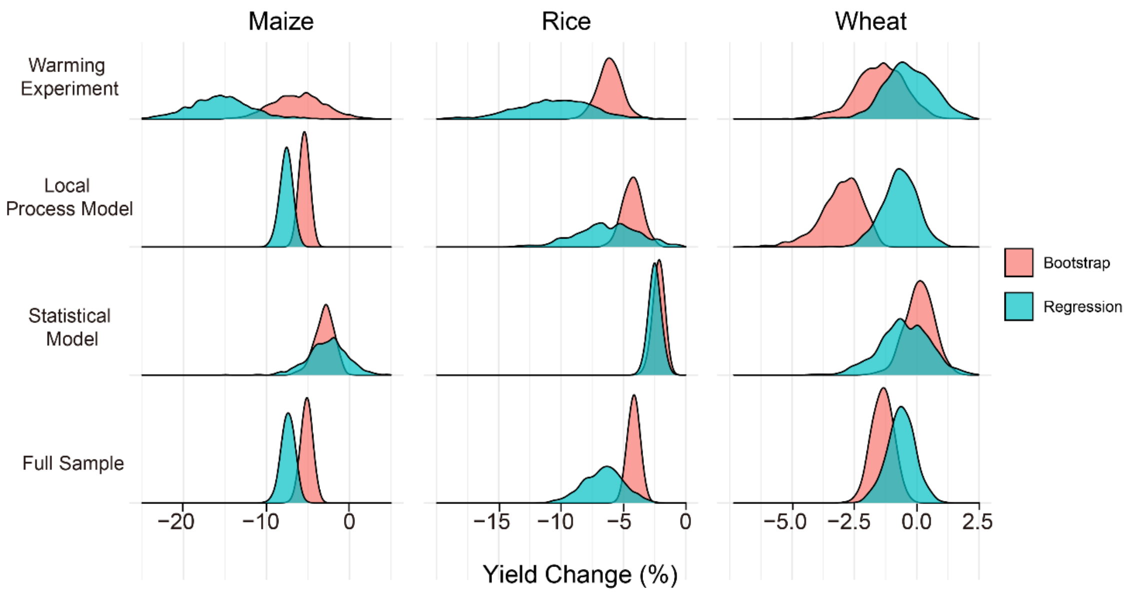

Fig. 1. The probability density distribution of climate change-induced yield damage functions, including two methods: bootstrap resampling and Meta-regression. From left to right, the chart represents three crops: maize, rice, and wheat. From top to bottom, it distinguishes different research approaches, including warming experiments, local process models, statistical models, and a full-sample model integrating all three approaches.

Significant variations were observed across the different research methods. In the warming experiments, maize and rice showed the highest yield losses, with median losses of 15.58% and 10.42%, respectively. In contrast, statistical models estimated lower losses of 2.58% and 2.49%, respectively. These differences may be attributed to the inclusion of socioeconomic adaptation factors in the statistical models, which mitigate the adverse impacts of climate change. CO_2 fertilization significantly influence the yield loss estimates. The meta-regression results revealed that when the CO_2 fertilization effect was considered, the median yield losses for maize, rice, and wheat were 3.65%, 3.71%, and 0.24%, respectively. Without CO_2 fertilization, the yield losses increased to 7.04%, 5.80%, and 3.21%, respectively.

Regarding the probability distribution of losses, warming experiments showed the most dispersed distributions with the largest variances, primarily due to variations in environmental factors (e.g., precipitation and CO_2 concentration) across experimental sites. By contrast, statistical models have the most concentrated distributions based on nationally uniform samples and consistent control conditions. The full-sample analysis incorporates the differences among the three methods, with the mean and variance of the loss distribution, and provides a more balanced result. This approach comprehensively assessed the yield loss risks for the three staple crops under climate change. Therefore, this study employs the climate change-induced loss functions derived from the full-sample model.

4.1.2 Yield loss estimation

We employed the climate change-induced loss function and China's projected temperature data to estimate the aggregated yield change of three major staple crops—maize, rice, and wheat—under different climate scenarios. The results are shown in Fig.3. Under the NP scenario, all three staple crops experienced the most severe output losses, with median yield losses of 10.91%, 9.31%, and 2.50% for maize, rice, and wheat, respectively. When considering the effects of CO_2 fertilization, these losses were reduced to 7.74%, 8.33%, and 0.43%, respectively. The output losses under the 2°C and 1.5°C scenarios show significant reductions for all three crops. Specifically, wheat, rice, and wheat exhibited output losses of 7.30%, 5.70%, and 2.41%, respectively, under the 2°C scenario and 5.52%, 3.36%, and 1.81%, respectively, under the 1.5°C scenario. A comparison of the three scenarios demonstrated that implementing climate policies can effectively reduce the output loss risks caused by climate change.

A t-test on the probability distribution of output loss confirms that losses under the 1.5°C scenario are significantly lower than those under the 2°C scenario. However, as shown in Fig.3g–Fig.3i, the avoided output losses from the NP scenario to the 2°C scenario are significantly greater than those from the 2°C scenario to the 1.5°C scenario. Stricter climate policies mitigate the impacts of climate risks. However, the marginal effects of policies with different levels of stringency require careful assessment.

The results in Fig.3a–Fig.3f indicate that the 1.5°C and 2°C scenarios show little difference in the overall range of output losses. For example, the maximum loss for wheat was approximately 5.7% for both scenarios. The main distinction lies in the spatial distribution of high-output-loss areas: the 2°C scenario exhibits a larger extent of high-loss regions concentrated in the major production zones of staple crops and southern regions that are more vulnerable to heat stress.

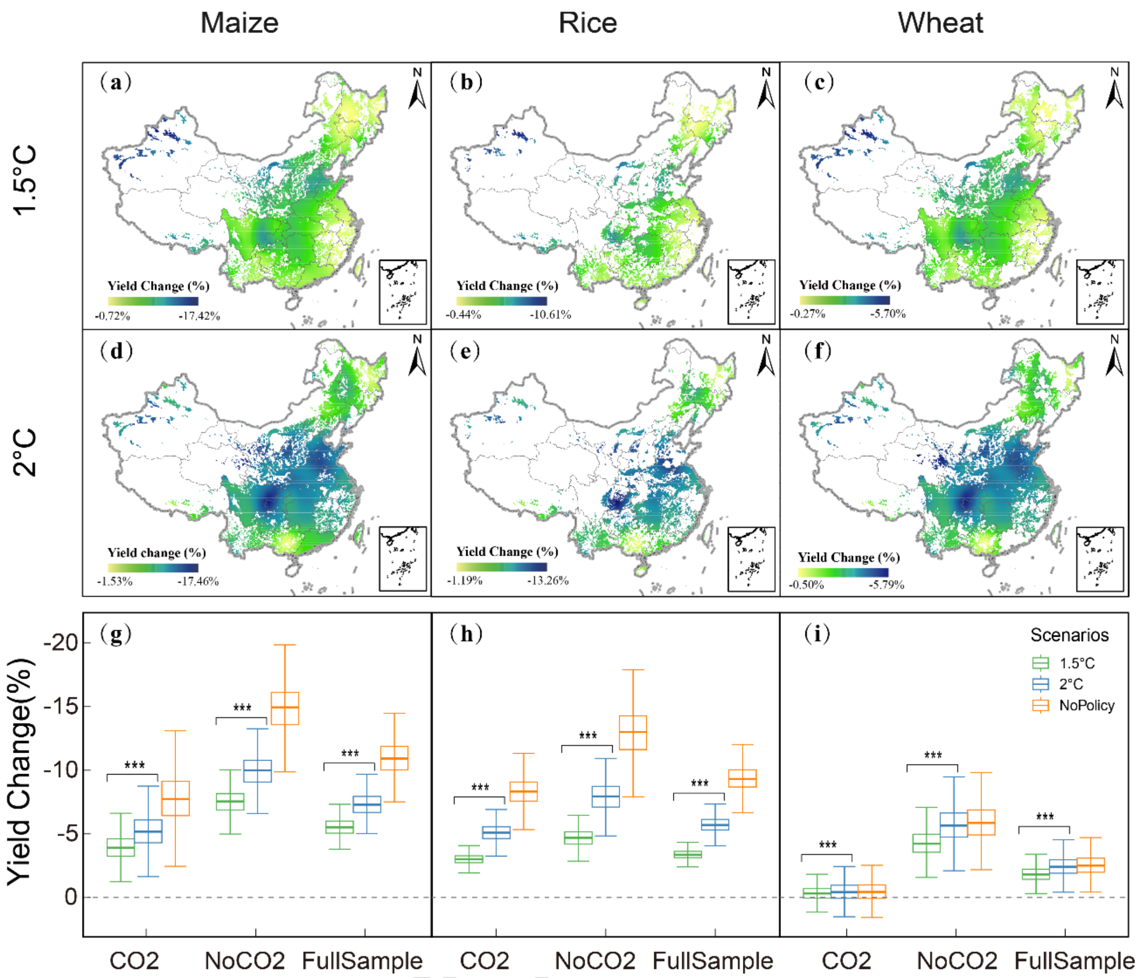

Fig. 2. Yield change distribution of staple crops under different scenarios. (a-c) Spatial distribution of yield change for rice, maize, and wheat under the 1.5°C scenario; (d-f) Spatial distribution of yield change for rice, maize, and wheat under the 2°C scenario; (g-i) Aggregated yield change distribution of rice, maize, and wheat under the 1.5°C, 2°C, and NP scenarios.

4.1.3 Impacts of climate change shock

Using the GTAP-E model, we further explored the impacts of climate change on the output, prices, household consumption, and self-sufficiency rates of major agricultural sectors in China. The results shown in Fig.4a demonstrate that global warming significantly negatively affects crop yields, leading to output losses. These findings align with the conclusions drawn from the loss function calculations: maize experienced the greatest losses, followed by rice and wheat. Notably, the reduction in staple crop yields also indirectly impacts livestock production; as some staple crops are used as livestock feed, their decreased output inevitably leads to a decline in livestock output.

In the NP (no-policy) scenario, the changes in agricultural product prices, household consumption, and self-sufficiency rates are more pronounced than in the 1.5°C and 2°C scenarios, posing greater risks to the stability of food markets and food self-sufficiency.

In contrast, under the 2°C and 1.5°C scenarios, implementing climate policies mitigates the declining trend in agricultural output to some extent, effectively controlling price fluctuations. For example, maize prices increased by approximately 70% under the 2°C scenario, whereas under the 1.5°C scenario, the increase was approximately 50%. Meanwhile, the decline in household consumption and self-sufficiency rates under the 2°C and 1.5°C scenarios is also smaller, both outperforming the NP scenario. This indicates that the implementation of climate policies not only reduces production losses but also alleviates price volatility and supply demand imbalances in the food market to some extent.

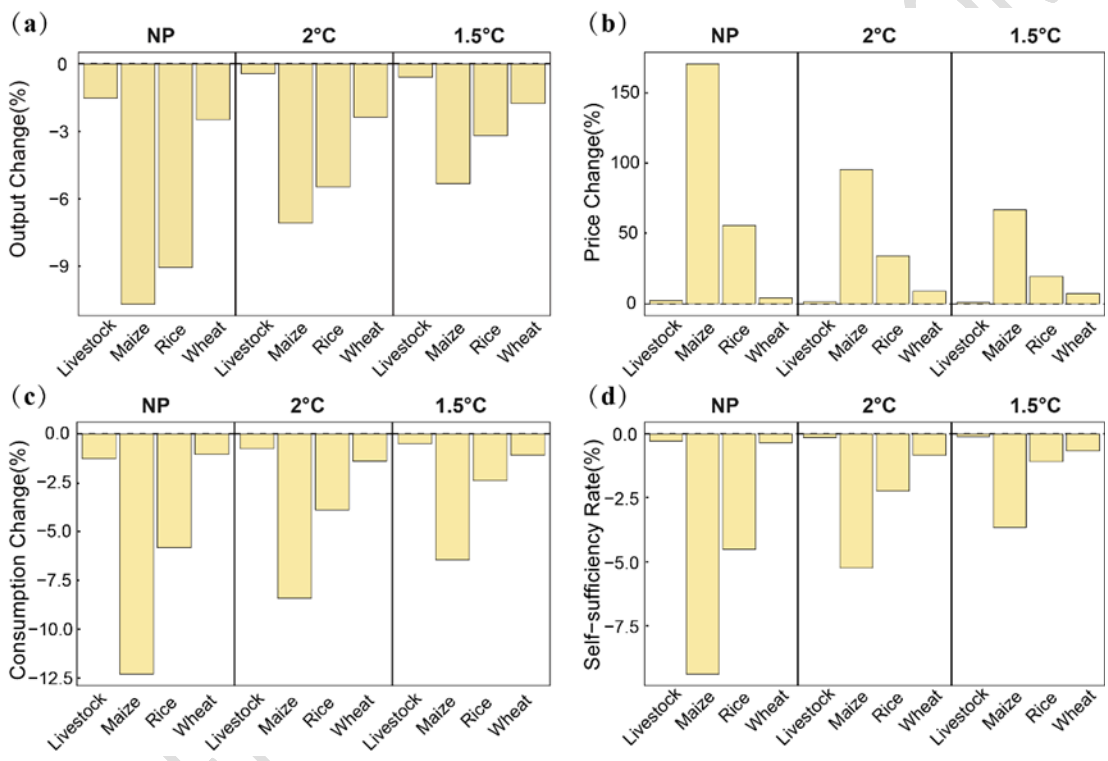

Fig. 3. Impact of Climate change shocks under NP, 2°C, and 1.5°C scenarios. The analysis includes the impacts of climate change shock on (a) output, (b) price, (c) household consumption, and (d) self-sufficiency of livestock, maize, rice, and wheat.

4.2 Transition-induced risks to agriculture

4.2.1 Low-carbon Transition Policies in agriculture

This study examines three main types of low-carbon transition policies that pose significant potential risks to agriculture: (1) occupation of arable land for solar energy infrastructure, (2) increased food demand driven by bioenergy development, and (3) rising costs associated with implementing agricultural GHG emission reduction measures.

A multi-model analysis shows that achieving the 2°C target requires China to install 13,316.41 GW of solar capacity by 2060, occupying 8,011.14 km² of arable land (0.71% of China's 2020 total) (Zhang et al., 2023). Under the 1.5°C scenario, this rises to 17,797.49 GW, using 12,151.64 km² (0.95% of arable land) (Zhang et al., 2023) (Fig.5a). This intensified land use would place additional pressure on land resources that are critical for food production. By 2060, bioenergy demands under the 2°C and 1.5°C scenarios are expected to increase to 19.30 EJ/yr and 22.56 EJ/yr, respectively. Bioethanol production will significantly increase corn demand, consuming an estimated 4.9% and 3.74% of the annual corn production under each scenario (Fig.5b) (Fujimori et al., 2019). Mitigating agricultural greenhouse gas emissions presents significant challenges: compared to the NP scenario, the 2°C and 1.5°C scenarios require 60% and 56% emission reductions, respectively. Under a uniform carbon pricing policy, the average carbon prices for these scenarios were estimated at \$549.7/t CO_2 and \$549.73/t CO_2, respectively (Fujimori et al., 2019) (Fig.5c Fig.5d).

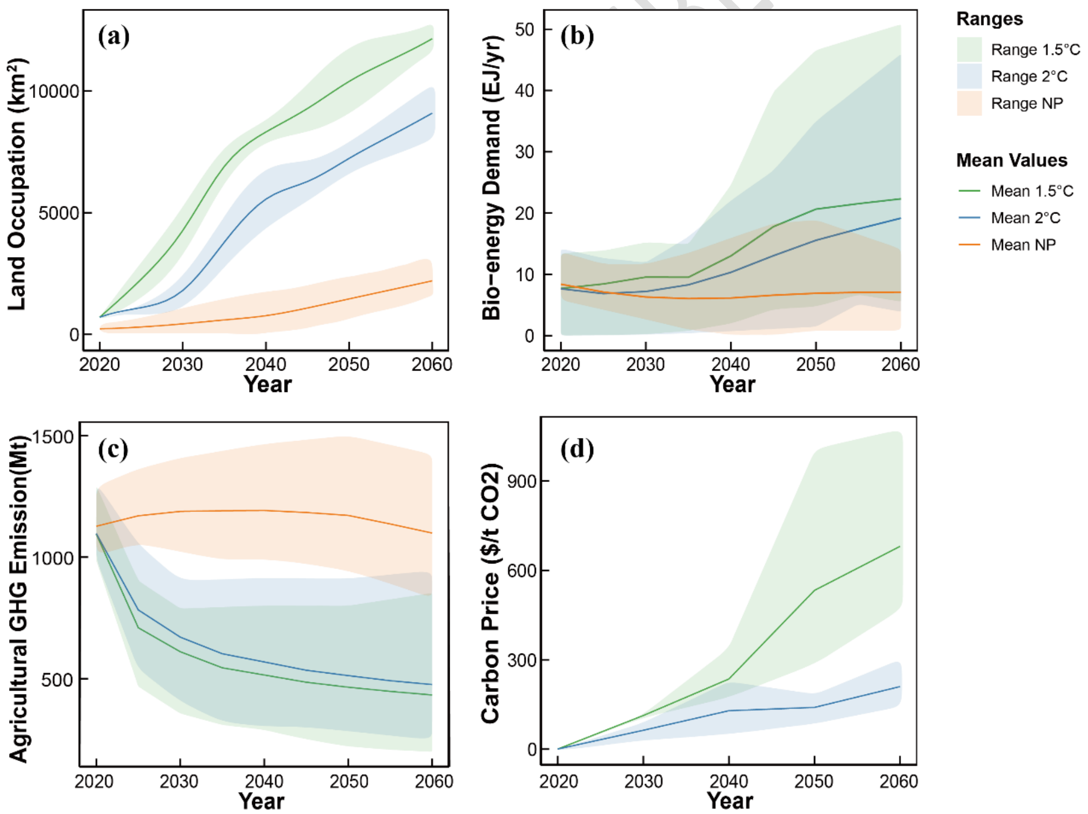

Fig. 4. Implementation pathways of transition policies from 2020 to 2060 under NP, 2°C, and 1.5°C scenarios:(a) Predicted cropland occupation by photovoltaic facilities; (b) Predicted demand for bioenergy; (c) Predicted emission pathways of agricultural GHG emission; (d) Predicted carbon price. The solid lines represent the average results from multiple models, while the shaded areas indicate the range of predictions across models.

4.2.2 Impacts of Low-carbon Transition Policies

We employ the GTAP-E model to analyze the impacts of low-carbon transition policies under the 2°C and 1.5°C scenarios on the production, prices, consumption, and self-sufficiency of livestock, maize, rice, and wheat. Overall, the agricultural sector faces greater production and consumption risks under the 1.5°C target than under the 2°C target. As shown in Fig.6a, in the 1.5°C scenario, production losses in livestock, maize, rice, and wheat were 2.35, 4.81, 4.95, and 4.66 times larger, respectively, than in the 2°C scenario. Meanwhile, to achieve deeper GHG emission reductions, the prices of both livestock and staple crops should rise considerably, reflecting higher production costs and reduced supply under stricter climate policies, which in turn drives prices upward.

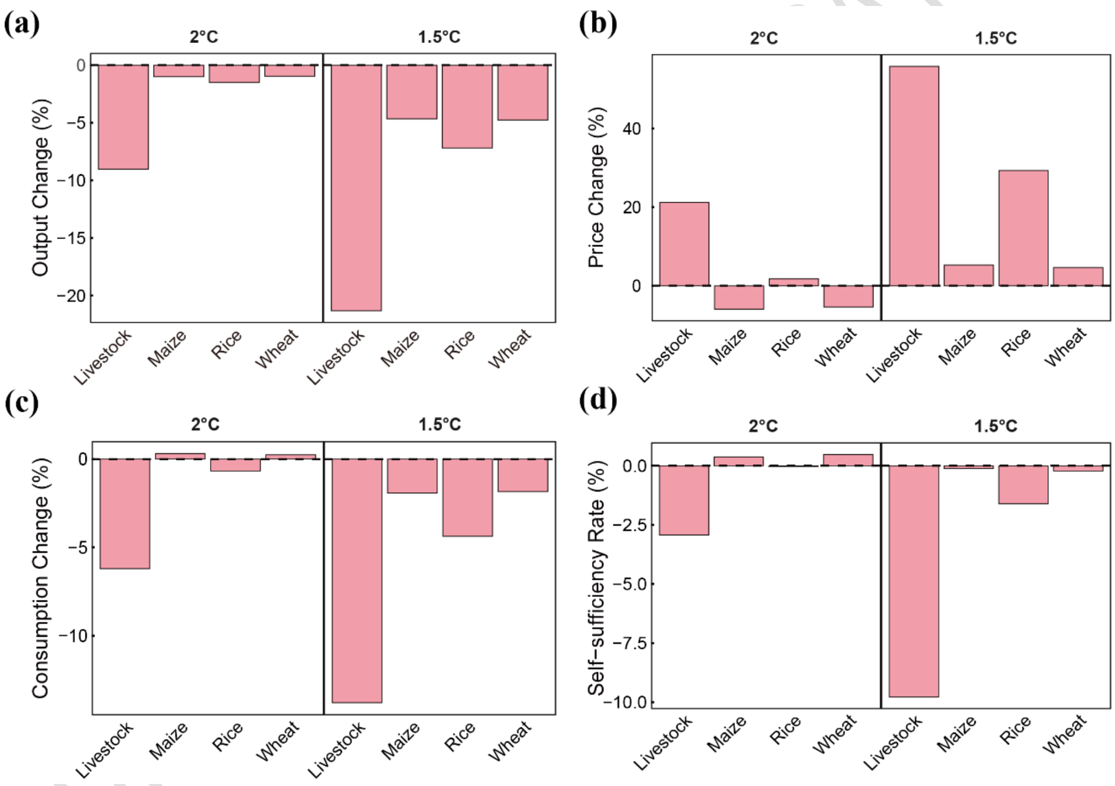

Fig. 5. Transition risks under 2°C and 1.5°C scenarios. The analysis includes the climate policies on (a) output, (b) price, (c) household consumption, and (d) self-sufficiency rate of livestock, maize, rice, and wheat.

Under the 2°C target, a sharp increase in livestock prices reduced meat consumption, while the consumption of staple crops (maize, rice and wheat) slightly decreased or remained stable, indicating a substitution effect through price signals. However, under the 1.5°C target, prices of both livestock and staple crops surge, imposing greater pressure on household food expenditures and resulting in a marked decline in the consumption of all four products. This finding highlights the stronger impact of stricter mitigation policies on increasing food prices and curbing consumption. Moreover, self-sufficiency rates decrease under both targets, with a more pronounced decline in the 1.5°C scenario, suggesting that domestic agricultural supply faces greater shocks under tighter emission reduction and transition policies. Consequently, reconciling the pursuit of more stringent emission targets with the need to maintain agricultural production and food security is a critical challenge that demands urgent policy and technological intervention.

4.3 Comparison of Climate Risks and Transition Risks

We further incorporated climate shocks under different scenarios into the GTAP-E model to comprehensively compare the climate and transition risks within China's agricultural sector under different scenarios. Owing to the absence of climate mitigation policies, the NP scenario would experience the greatest impact of climate change on agricultural production, causing notable declines in the output of major crops. These output losses could trigger a sharp increase in staple crop prices, with maize prices increasing by 170.64% and rice prices increasing by 55.76% (Fig.7a). Consequently, household consumption and self-sufficiency rates for staple crops might drop, which would lead to greater dependence on imports and increase the risks to national security. In the 1.5°C scenario, more ambitious mitigation targets would require rigorous transition policies, which could impose substantial risks on agriculture. Due to the cost increases caused by climate policies, significant declines in output are observed across various agricultural sectors. The reductions in household consumption and self-sufficiency rates were similar to those observed in the NP scenario (Fig.7c–Fig.7d). Notably, under the 1.5°C Scenario, livestock would face the greatest impacts among the three scenarios, with the highest levels of production losses, price fluctuations, consumption reductions, and self-sufficiency declines (Fig.7). These changes would significantly amplify the risk of insufficient protein intake in China.

Compared to the NP and 1.5°C scenarios, the impacts of climate change and transition policies under the 2°C scenario were relatively moderate. Under the 2°C scenario, China's agriculture would be affected by both climate change and transition policies, but their impacts would be far less significant compared to the NP and 1.5°C scenarios. Declines in production, household consumption, and self-sufficiency were lowest among the three scenarios (Fig.7). While price fluctuations would be similar to those in the 1.5°C scenario, livestock prices would remain more stable, and the price increases for staple crops would also be relatively smaller (Fig7b). Compared with the other scenarios, China's agriculture would maintain greater stability and self-sufficiency under the 2°C scenario.

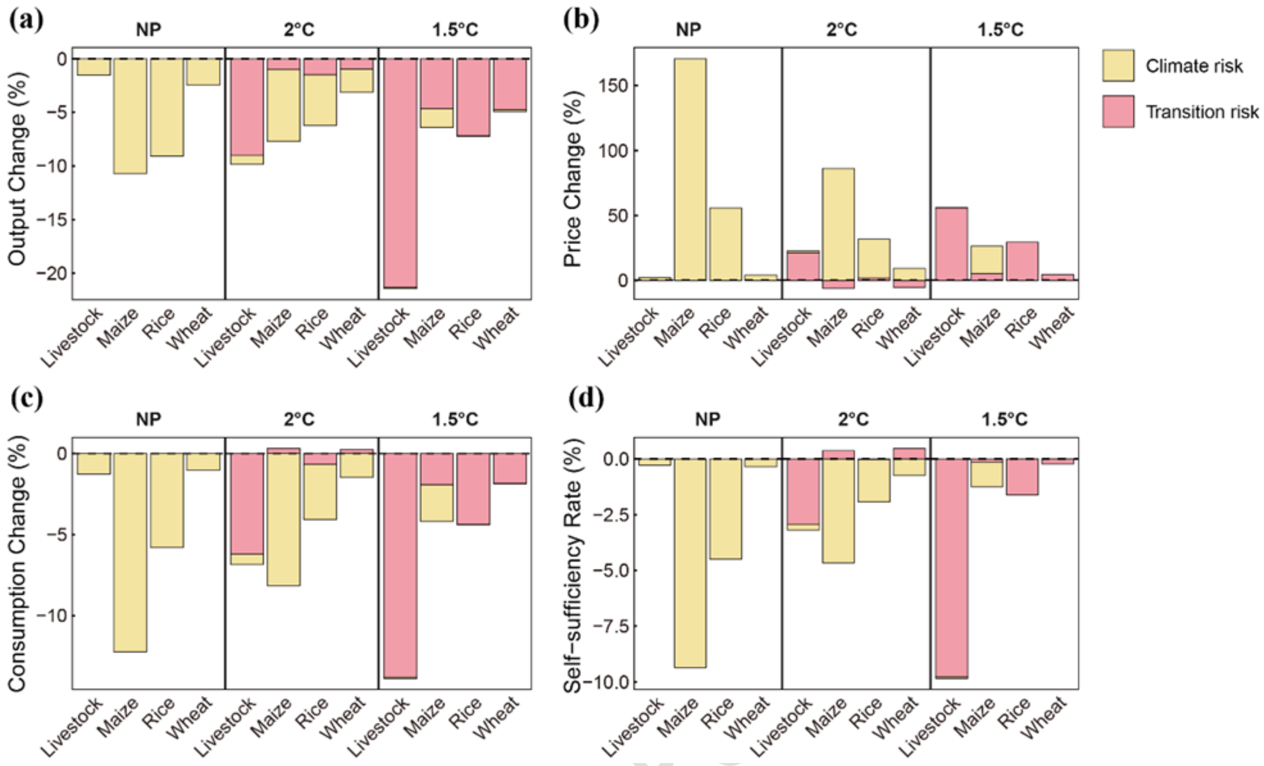

Fig. 6. Comparison of climate risks and transitions under NP, 2°C, and 1.5°C scenarios. The analysis includes the impacts of climate change and transition policies on (a) output, (b) price, (c) household consumption, and (d) self-sufficiency of livestock, maize, rice, and wheat.

5. Conclusion and Discussion

This study comprehensively analyzes China's agricultural risks under the 1.5°C and 2°C scenarios. The results show that China's agriculture is vulnerable to climate change, with staple crops such as maize, rice, and wheat facing significant yield losses under the NP (no policy) scenario. However, implementing climate policies, especially under the 1.5°C and 2°C scenarios, significantly reduces these climate-induced risks by mitigating yield losses. Nevertheless, these policies also introduce transition risks such as the occupation of cropland by renewable energy projects and cost increases due to carbon taxes, which may negatively impact on agricultural output, prices, household consumption, and self-sufficiency rates. Notably, while the 1.5°C scenario is more effective in reducing climate risks, it brings greater transition risks than the 2°C scenario. In this scenario, agricultural output, household consumption, and self-sufficiency declined more significantly, and agricultural product price fluctuations were more severe. However, the 2°C scenario achieves a balance between mitigating climate risks and transition risks, with relatively milder impacts on agriculture. When promoting low-carbon agricultural transition, a balance must be struck between climate goals and agricultural stability, considering regional differences and the time dimension of risks. Additionally, governments and relevant stakeholders should comprehensively assess all risks that may arise during the low-carbon agricultural transition process. Ignoring these risks can significantly threaten food security in large populations.

The current agricultural risk assessment methods still have significant room for improvement, particularly in dynamic risk assessment and cross-period comparisons. The transition risks faced by agriculture and climate risks have different time characteristics: transition risks are mainly concentrated in the short term, while climate risks are long-term and gradual (Gambhir et al., 2022). Therefore, risk assessment should further integrate a risk-discounting mechanism to scientifically weigh short- and long-term risks. At the same time, the low-carbon transition of agriculture is not only a response to risks, but may also bring multiple positive effects, especially in enhancing production efficiency and advancing agricultural modernization (Chandio et al., 2025). Based on this, future policy evaluations should adopt a more comprehensive perspective and accurately assess short-term risks while fully considering potential long-term benefits, thereby achieving a comprehensive balance of risks and rewards.

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