The Economics of Ecosystem and Biodiversity (TEEB): Promoting a Sustainable Agriculture and Food Sector (China)

Report for the Heilongjiang "Soybean Expansion" policy study

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Contents

1. Background

"The Economics of Ecosystems and Biodiversity: Promoting a Sustainable Agriculture and Food Sector" project's second application in China[1] focuses on the national soybean expansion policy and chooses Heilongjiang Province as the study area to model and forecast the natural, economic and social impacts of the differences in land use brought about different soybean expansion policies (hereafter "the Heilongjiang study").

This report is the third in a series of reports of the Heilongjiang study. The first, the scoping and scenario setting report, includes a comparison of alternative future development scenarios, driven by agriculture policy priorities, climate change, demographic change, and urbanization, that will be assessed by the TEEBAgriFood evaluation framework. The second, data and methodology report, includes an outline of the processes and methodologies that will be used by the research team to measure and value the dependencies and impacts of the implementation of the soybean expansion policies in the province. This report presents the integrated scenario modelling and valuation results of the Heilongjiang study.

2. The policy context and study area

Heilongjiang Province, located in Northeast China, has a total area of 473,000 km^2, ranking 6th in the country. The regional gross domestic product (GDP) in 2020 was 1,369.85 billion CNY, with the proportion of the primary industry accounting for 25.1%, much higher than the national average (7.7%). According to the grain production data released by the National Bureau of Statistics, Heilongjiang Province had 14.68 million hectares of grain crops planted by 2022, accounting for 12.4% of the country, and total grain production of 77.63 billion kg, accounting for 11.3% of the country, ranking first in the country for thirteen consecutive years.

Heilongjiang has excelled in the cultivation of the three major grain crops: maize, rice, and soybeans. All these three crops account for over 95% of the planted area of grain crops in Heilongjiang Province. In the year 2020, Heilongjiang's soybean planting area alone encompassed a staggering 4,832,000 hectares, representing a third of the province's total planting area—a figure that significantly surpassed national averages

[1] The research has been made possible with the funds and support from the European Union through the European Union Partnership Instrument (EUPI), and continuous guidance from United Nations Environment Programme (UNEP) TEEB Office.

and surpassed other provinces. Over the past decade, Heilongjiang has consistently contributed more than 40% of the nation's soybean planting area and production, with some years even reaching 50%. This remarkable track record has firmly established Heilongjiang as a cornerstone of soybean production in China, underscoring its vital role as a key soybean production base within the country.

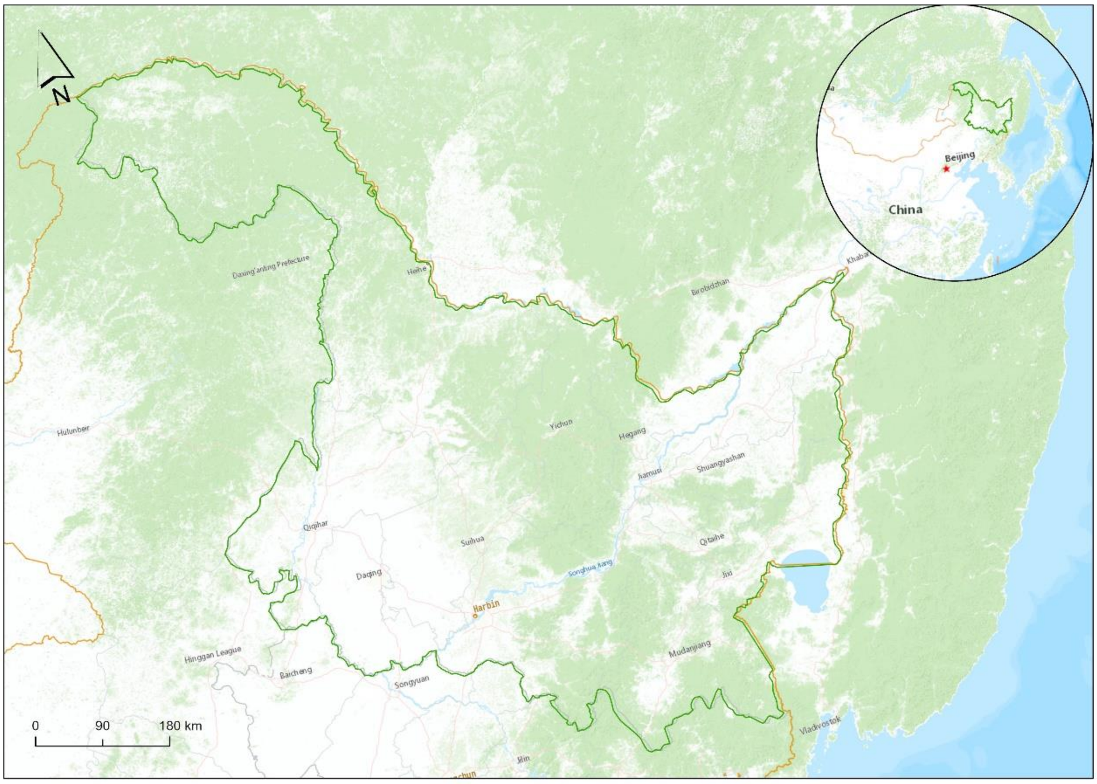

Figure 2.1 Geographic location of Heilongjiang Province

As the economy develops and people's living standards improve, the consumption of protein and oil-rich foods increases. Soybeans are an important source of plant protein and oil, and soybean meal is also an important feedstock. China’s demand for soybeans continues to increase. From 2010 to 2020, soybean demand increased from 70.20 million tons to 119.92 million tons (an increase of 71%). The majority of the growth was supplemented by imports. As the global and national trend of substituting red meat by plant-based products prevails, it is very likely that the demand for soybean continues to increase. In recent years, the uncertainty of soybean supply such as climate change and geopolitics has increased. In order to cope with the increase in domestic soybean demand and enhance the resilience of the food systems, the Chinese government is seeking solutions such as moderately expanding soybean planting in suitable regions. According to stakeholder consultation and related government documents, the “soybean expansion” practice in Heilongjiang will be conducted through “paddy to soy” and “maize to soy” transitions, considering the majority (95%) of farmland is occupied by paddy rice, maize and soybean.

Soybean expansion requires careful planning and substantial policy support. This policy factor underscores the intricate interplay between government interventions and agricultural practices, and it raises critical questions about how these policies impact not only crop provisioning but also the broader environmental and socio-economic fabric of the agrifood system. Analysing the dynamics of this policy and its consequences is integral to understanding the future of agricultural land use and its implications for food security, environmental sustainability and economic development.

3. Scenario setting

3.1 Drivers and timeline

The driving forces that affect the agricultural system can be divided into two categories: natural environmental factors and social and economic factors. For socio-economic factors, this study focuses on policy factors which includes agricultural policies and other land-use policies, as well as non-policy factors such as GDP, population change, and urbanization.

In terms of natural environmental factors, the study considers changes in natural environmental elements caused by climate change, using the regional temperature and precipitation conditions under two representative concentration pathways (RCP4.5 and RCP8.5) in the Fifth Assessment Report of the Intergovernmental Panel on Climate Change (IPCC) as indicators of future climate change scenarios.

In terms of agricultural policy factors, this study considers a complex web of policies and incentives that guide farmers' decisions. In this context, one of the pivotal policy initiatives under scrutiny is the “soybean expansion” policy. This multifaceted policy aims to catalyse a significant shift in agricultural land use, encouraging farmers to prioritize soybean cultivation over other staple crops like maize and paddy rice.

Other land-use policies include forest protection laws and regulation on the protection of basic farmland, and the study assume they remain in force across all scenarios.

The short-term time point of this study is 2025, which is the completion year of China's "14th Five-Year Plan" and the first five-year period to achieve a moderately prosperous society[2] and improve the quality and efficiency of agriculture. The mid-term time point is 2035, which is the target year for China to basically achieve modernization and an important node for achieving modern green production and sustainable consumption. The long-term time point is 2050, which is the target year for China to achieve its second centennial goal, i.e., to build a prosperous, democratic, culturally advanced, harmonious, and beautiful socialist modernized strong country by the centenary of the founding of the People's Republic of China.

Based on the abovementioned agricultural and forestry policy orientation during the "14th Five-Year Plan" period, this study sets three policies pathways: "BAU", "soybean priority (SP)", and "grain priority (GP)"[3]. The scenario analysis attempts to depict the differences in the natural, economic and social costs and benefits of following the different pathways in Heilongjiang throughout the three key time points. The study also integrates other socio-economic drivers into modelling, such as future trends driven by soybean breeding improvement, specialized cultivation, reducing pesticide and fertilizer use, and promoting conservation tillage.

The BAU policy pathway represents the most likely changes in Heilongjiang's agrifood system under the current policy orientation and planning, that is, moderately expanding soybean cultivation on the existing planting mode and basis. The setting of parameters of the BAU scenario is as follows (Table 3.1).

Table 3.1 Soybean production data under the BAU scenario

Year	Cultivated area (10,000 ha)	Yield (t/ha)	Fertilizer efficiency (%)	Pesticide efficiency (%)	No-till rate (%)	Production (10,000 t)
2022	493.17	1.93	40.2	40.6	0	951.82
2025	471.93	2.51	45	45	20	1184.54
2035	502.815	2.70	50	50	50	1357.60
2050	502.815	2.90	50	50	70	1458.16

2022 data sourced from https://www.hlj.gov.cn/hlj/c107856/202212/c00_31502977.shtm

[2] Building a moderately prosperous society is a grand strategy since the 1980s aimed at realizing national prosperity, rejuvenation, and ensuring people's well-being. Based on an analysis and judgment of the reality of China at that time, the Communist Party of China decided to focus on economic development and drive progress in all social aspects. Subsequently, building a moderately prosperous society in stages became an important goal. In 2021, China announced that it had achieved the goal of building a moderately prosperous society in all respects, a critical step towards realizing the Chinese dream of national rejuvenation.

[3] Grain includes to paddy rice, maize, and wheat. In the case, it mainly refers to paddy rice and maize. Soybean is one kind of oil crop.

The SP pathway represents a bold expansion of soybean cultivation compared with the BAU. The setting of parameters of the SP scenario is shown in Table 3.2.

Table 3.2 Soybean production data under the Soybean priority scenario

Year	Cultivated area (10,000 ha)	Yield (t/ha)	Fertilizer efficiency (%)	Pesticide efficiency (%)	No-till rate (%)	Production (10,000 t)
2022	493.17	1.93	40.2	40.6	0	951.82
2025	815.54	2.51	45	45	20	2047.01
2035	1495.41	2.70	50	50	50	4037.61
2050	1494.89	2.90	50	50	70	4335.18

Here X represents the converted area of water-intensive rice cultivation to soybean cultivation in groundwater overexploited areas (to be determined in land-use modelling), while Y represents the soybean planting area in 2025 calculated based on the soybean planting area growth trend from 2021 to 2035. Total production in 2025, 2035, and 2050 are to be modelled (TBM).

The GP pathway considers a conservative status of soybean expansion, prioritizing maize and paddy rice productions. Soybean yield, fertilizer utilization rate, pesticide utilization rate, and no-tillage adoption rate will all be maintained at the current levels. The utilization rate of fertilizers and pesticides will be 40.2% and 40.6%, respectively, and the no-tillage adoption rate will be 0.

Table 3.3 Soybean production data under the Grain priority scenario

Year	Cultivated area (10,000 ha)	Yield (t/ha)	Fertilizer efficiency (%)	Pesticide efficiency (%)	No-till rate (%)	Production (10,000 t)
2022	493.17	1.93	40.2	40.6	0	951.82
2025	471.93	1.93	40.2	40.6	0	910.82
2035	502.82	1.93	40.2	40.6	0	970.44
2050	502.82	1.93	40.2	40.6	0	970.44

In total, the Heilongjiang study considers six scenarios formed by the intersection of three soybean development pathways and two climate change pathways at three time points (Table 3.3).

Table 3.3 Scenario setting

Scenario 1	Scenario 2	Scenario 3
RCP4.5 + BAU	RCP4.5 + Soybean priority	RCP4.5 + Grain priority

Scenario 4	Scenario 5	Scenario 6
RCP8.5 + BAU	RCP8.5 + Soybean priority	RCP8.5 + Grain priority

3.2 Coexisting smallholder and large-scale farming modes

Two representative production modes exist in the study region. Smallholder and large-scale farming cooperatives. Smallholder modes are generally operated at the household level, relying on family members for the day-to-day operations and often kinships during the busy seasons. Large-scale farming exists in the form of farming cooperatives with management structures closely resembling those of industries. Here household-owned land is pooled together to form large patches of land dedicated for monoculture, while households themselves sometimes work as "employees", mainly operating machineries.

Large-scale mechanized farming has been replacing smallholder farming methods for reasons such as productivity and efficiency, and most importantly, the economies of scale, enabling access to larger markets and potentially increasing the income of farmers participating in the transition. However, due to differences in the cultivation characteristics between the two modes (Figure 3.1), such changes will instigate changes in the produced, human, and social capitals. Therefore it is important to categorize and quantify the accompanying changes for subsequent analysis.

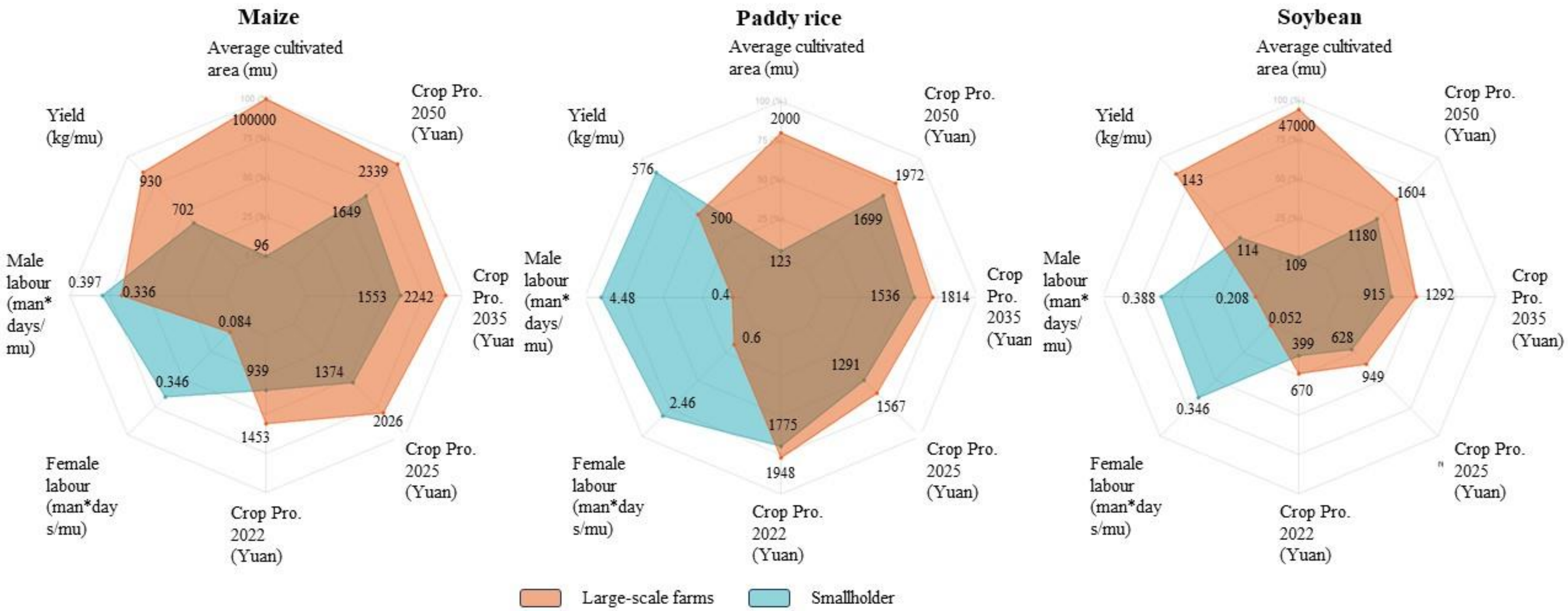

Figure 3.1 Major input and output characteristics of the three main crop types. RV: residual value per mu. Mu: area unit of 667 m^2.

Figure 3.1 details the specific differences between smallholder and large-scale mechanized cultivations modes among maize, paddy rice, and soybean crops. The specifics are as follows:

In the case of maize cultivation, the large-unit mode involves significantly larger average cultivation areas compared to smallholder farms. While smallholder farms have an average cultivation area of 95.6 mu (15 mu equals 1 hectare), large-unit farms on average cover a vast expanse of 100,000 mu. This indicates a substantial shift toward mechanized and industrial-scale production in the large-unit mode. Consequently, large-unit farms exhibit higher average yields per mu, with 930 kg/mu, whereas smallholders yield 702.04 kg/mu. The labour requirement is notably lower in the large-unit mode, with 0.34 man*days for males and 0.08 man*days for females, compared to 0.40 man*days for males and 0.35 man*days for females in smallholder farms. This transition to large-unit production results in higher crop provisioning services in 2022, with a substantial increase projected for 2025, 2035, and 2050 (Figure 3.1).

For paddy rice cultivation, the differences between smallholder and large-unit modes are evident. Large-unit farms cover a considerably larger average cultivation area, with 2000 mu, compared to 123.333 mu for smallholders. This shift toward large-unit production leads to a relatively lower average yield per mu in the large-unit mode (500 kg/mu) compared to smallholder farms (575.64 kg/mu). Labor requirements differ significantly, with smallholder farms needing 4.48 man*days for males and 2.46 man*days for females per mu, while large-unit farms require only 0.4 man*days for males and 0.6 man*days for females. Despite the differences, both modes exhibit an increase in crop provisioning services over time, with large-unit farms consistently showing higher values (Figure 3.1).

In the case of soybean cultivation, the transition to large-unit production is associated with an even more substantial increase in average cultivation area. Large-scale soybean farms on average cover 47,000 mu, while smallholders cultivate an average of 108.6 mu. Large-scale production also results in a higher average yield per mu (142.8 kg/mu) compared to smallholders (114 kg/mu). The labour requirement in the large-unit mode is considerably lower, with 0.21 man*days for males and 0.05 man*days for females, in contrast to 0.39 man*days for males and 0.35 man*days for females in smallholder farms. Furthermore, the crop provisioning services are consistently higher in large-unit soybean production over the years (Figure 3.1).

The average ratio of large-scale farms to smallholder production for all three crops (paddy rice, maize, and soybean) in 2022 was 4:6. Assuming a continued transition towards large-scale production driven by factors such as the need for increased efficiency, higher yields, and the potential for cost savings, we projected that the ratio will change to 5:5 in 2025, to 6:4 in 2035, and ultimately to 7:3 in 2050 (determined using survey questionnaires and interviews with farmers and rural authorities).

4. Data and methods

4.1 Content of analysis

This study adopts the TEEBAgriFood evaluation framework to comprehensively assess the monetary costs and benefits of maize, paddy rice, and soybean cultivation in the four capitals, namely natural, human, social, and produced capitals. This framework provides a structured and holistic approach to understanding the multi-dimensional impacts of agricultural activities on these vital capitals, enabling a more nuanced and informed analysis of the agri-food system in Heilongjiang Province.

The TEEBAgriFood framework recognizes that the agri-food sector is not merely an economic entity, but a complex system deeply intertwined with ecological, social, and human dimensions. By evaluating the impacts across the four capitals, this methodology goes beyond traditional economic assessments and considers the broader implications of agricultural practices. It allows us to account for not only the market values of crops but also their environmental, social, and human health-related costs and benefits. Based on stakeholder consultation, we include benefits and costs falling into four categories of capitals from the following aspects.

Regarding the benefits derived from natural capital, the analysis encompasses ecosystem regulation services, notably water provisioning, water purification, soil retention, carbon sequestration, and pollination (assessed using relative abundance index, which is unitless and does not translate to monetary values; Table 4.1). Furthermore, our cost analysis extends to encompass the emissions of air, water, and solid pollutants, as well as greenhouse gas emissions. Detailed methodologies and formulas for the calculation of each specific ecosystem service can be found in Table 4.3, providing a comprehensive framework for assessing their respective contributions and impacts.

Produced capital benefits included in the analysis consist of crop production outputs, while costs include various agricultural inputs such as energy, fuel, fertilizer, and pesticides.

Human capital represents "the knowledge, skills, abilities, and attributes that are embodied in individuals and that contribute to their personal, social, and economic well-being" (TEEBAgriFood), including health, education, job skills, traditional knowledge, etc. This study analyses the benefits in terms of labour quantity and salary, as well as the health costs associated with occupational exposure, air pollution exposure, downstream water body exposure, and agricultural product consumption exposure. The accounting methods and formulas for calculating health costs are detailed in Table 4.3.

Social capital includes "the networks, norms, values, and understandings that facilitate cooperation within and between groups" (TEEBAgriFood). It can be viewed as a capital form that facilitates the production and distribution of other forms of capital. It includes various rules and regulations, customs, traditions, culture, social equality, cultural diversity, etc. This study qualitatively analyses the benefits of social capital from the perspectives of women empowerment and social mechanisms (agricultural cooperatives). The data on female empowerment mainly includes the number of female laborers in the agricultural food system and their wages. The benefits and costs of agricultural cooperatives in Heilongjiang are estimated based on the projected number of cooperatives engaged in crop production and the different input/output characteristics, which were gathered during stakeholder interviews.

Table 4.1 Content of analysis

Capital	Benefit	Cost
Natural	Ecosystem services: water provisioning, water purification, soil retention, carbon sequestration, pollination	Pollutant emissions: air pollutants (ammonia nitrogen, nitrogen oxide, nitric oxide, nitrogen dioxide, methane, pesticides), water pollutants (chemical oxygen demand, nitrate, phosphate, pesticides), solid waste (unused straw, animal excrement), and greenhouse gases over the entire life cycle
Produced	Crop production	Input of agricultural materials (energy, fuel, fertilizers, pesticides, etc.)
Human	Quantity and salary of labour force	Health impacts: occupational exposure, exposure to air pollution, exposure to downstream water bodies, and exposure to consumption of agricultural products.
Social	Women empowerment, social mechanisms (agricultural cooperatives)	/

4.2 Analysis methods and data sources

The project collects data and information from local governments, agricultural cooperatives and farmers through field interviews, online communication and literature review, covering agricultural industry information, related policy or planning documents, and parameters of agricultural inputs and outputs.

Data on the inputs and outputs of cultivation of soybean, maize and paddy rice in Heilongjiang was collected through face-to-face interviews with representative farms, cooperatives and households in May 2023. The interviews revolved around the following aspects – i) arable land conditions and farming practices, ii) inputs and expenditures, iii) products and sales, iv) institution support, and v) attitude towards soybean expansion.

Spatial data and census data, including land cover data, geographic information data, socio-economic data and climate prediction data, were acquired through open data platforms. The specific data and methodology are as follows (detailed calculations can be found in Annex 1):

4.2.1 Land-use and Land-cover (LULC) modelling

The study considers three scenarios based on the "soybean expansion" policy and climate change scenarios (RCP4.5 and RCP8.5) in Heilongjiang Province. These scenarios include a business-as-usual (BAU) scenario, a soybean priority (SP) scenario, and a grain priority (GP) scenario. Each scenario involves changes in crop planting patterns, and the model accounts for variations in soybean yield due to differences in water and temperature conditions. The research provides a comprehensive framework for understanding the potential impacts of different land use and climate scenarios on soybean production in the region.

This research used the FLUS model to simulate changes in crop layouts, considering different greenhouse gas emission targets represented by RCP4.5 and RCP8.5 scenarios. The FLUS model integrates artificial neural networks (ANN) and a roulette wheel selection mechanism into a System Dynamics (SD) and Cellular Automaton (CA) framework. It is suitable for simulating land use change scenarios under various driving forces, including natural, social, and economic factors. The model combines different data types and effectively handles complex, multivariate information, enabling it to integrate various driving factors and establish relationships between land use types and these factors. Additionally, it introduces an innovative selfadaptive inertia and competition mechanism based on roulette wheel selection, which deals with uncertainty and complexity in land use changes resulting from multiple driving forces, ultimately achieving high-precision land use change simulations. Climate change characteristics included rainfall and temperature factors. Different scenarios for future crop types and constraints were set, simulating changes in crop layouts for 2025, 2035, and 2050 for the business as usual, soybean priority, and grain priority scenarios.

The precipitation and temperature data for the RCP4.5 and RCP8.5 scenarios were obtained from the Chinese climate projections based on RegCM4.6 (2007-2099) (see Pan and Zhang, 2020; Pan et al., 2020). Spatial and census data, including land cover type data, basic geographic information, socio-economic data and climate projection data, were obtained through open data platforms. Table 4.2 lists the data types and their sources.

Table 4.2 Multivariate data for land use land cover change modelling

Data Type	Indicators	Year	Data accuracy	Data source
Land Use Data	Land Use	2000-2022	30 m	Resource and Environmental Science and Data Center, Chinese Academy of Sciences (http://www.resdc.cn/)
Socio-economic drivers	Administrative boundaries			
	GDP	2015	1000m	Resource and Environmental Science and Data Centre, Chinese Academy of Sciences (http://www.resdc.cn/)
	Population	2015	100m	WorldPop (www.worldpop.org/)
	Distance from administrative centre	2015	30m	National Center for Basic Geographic Information (www.webmap.cn)
	Distance to main roads	2015	30m	National Center for Basic Geographic Information (www.webmap.cn)
	Distance to motorways and railways	2015	30m	National Center for Basic Geographic Information (www.webmap.cn)
Natural drivers	Digital Elevation Model (DEM)	2015	30m	Resource and Environmental Science and Data Centre, Chinese Academy of Sciences (http://www.resdc.cn/)
	Slope	2015	30m	Based on DEM
	Slope direction	2015	30m	Based on DEM
	Soil type	1995	1000m	FAO (www.fao.org/)

	Distance to water system	2015	30m	National Center for Basic Geographic Information (www.webmap.cn)
	Temperature	2015	1000m	Resource and Environmental Science and Data Centre, Chinese Academy of Sciences (http://www.resdc.cn/)
	precipitation	2015	1000m	Resource and Environmental Science and Data Centre, Chinese Academy of Sciences (http://www.resdc.cn/)
Future climate scenarios	Temperature	2020-2035	0.25°	National Qinghai-Tibet Plateau Data Centre (data.tpdc.ac.cn)
	Precipitation	2020-2035	0.25°	National Qinghai-Tibet Plateau Data Centre (data.tpdc.ac.cn)

4.2.2 Natural capital assessment

The ecosystem service benefits from natural capitals include water provisioning services, water purification services, soil retention services, pollination, and carbon sequestration.

Water provisioning services. Freshwater is an irreplaceable natural resource for industrial and agricultural production, economic development and environmental improvement, and it is an ecosystem service that provides multiple social benefits to humans. The water production capacity of an ecosystem depends on the dynamic hydrological cycle within the system. It is influenced by climate, soils, vegetation, topography and land use structure to show variation. This study uses the InVEST water yield model to estimate the relative contribution of water from different parts of the landscape, analysing how land use patterns affect annual surface water yields. The economic value of water-supporting services is calculated by multiplying surface water yield by the local price of water. It is calculated as value = physical quantity × water price of 3.45 Yuan/m3 (Table 4.3).

Water purification services. The material-energy cycles of ecosystems have a processing and purifying effect on the quality of the water environment. Changes in land use, particularly the shift to agricultural land, significantly alter the natural nutrient cycle. When the impact exceeds the capacity of ecosystems to cleanse themselves, the decline in water quality will directly impact human well-being and health. The water quality purification module of the InVEST model uses a mass conservation approach to simulate the spatial mass transport of nutrients. The spatial transport of N and P nutrients from the outside world to the surface and then to rivers and lakes are analysed at the catchment scale, characterising the magnitude of the retention service capacity of N and P nutrients by different cover conditions on the surface as well as the transport processes and patterns. The corresponding treatment costs of N and P estimate the economic value of the final water purification service. It is calculated as value = physical quantity × water treatment cost for N (1500 Yuan/t) and P (2500 Yuan/t), respectively (Table 4.3).

Soil retention services. Erosion and terrestrial sediment retention are natural processes regulating stream sediment concentrations. Sediment dynamics at the catchment scale are mainly determined by anthropogenic factors such as climate (especially rainfall intensity), soil characteristics, topography and vegetation, and agricultural activities. Ecological factors in the ecosystem (e.g. vegetation cover) enhance the prevention of soil erosion, prevent soil runoff from entering the river and help maintain the soil's ability to filter pollutants and regulate water quality. This study uses the InVEST sediment transport model to estimate annual soil loss and sediment transport rates spatially, to derive further the loss of beneficial elements (nitrogen and phosphorus) from the soil that can be avoided by soil control, and to calculate the value derived from erosion control with the corresponding fertiliser prices. It is calculated as value = physical quantity × respective nutrient loading factor (0.10% for N and 0.04% for P) × corresponding nutrient loss equivalent values (N fertiliser at 1776.85 Yuan/t, P fertiliser at 2351.25 Yuan/t; Table 4.3).

Carbon sequestration services. Ecosystems regulate the Earth's climate by increasing or decreasing atmospheric greenhouse gases such as carbon dioxide. Ecosystems can release large amounts of carbon dioxide through fire, pests and diseases, and vegetation type conversion (e.g. land use/land cover change). By accumulating carbon in plants and soils, ecosystems can 'sequester' additional carbon each year. This study uses the InVEST carbon sequestration model to estimate carbon sequestration in four main carbon pools (above-ground biomass, below-ground biomass, soil and dead organic matter) under different land uses. The economic value of carbon sequestration services was calculated at a rate of 28.6 Yuan/t[4] CO2 equivalent (Table 4.3).

Pollination services. Pollination of crops by bees and other animals is an ecosystem service found in many mixed agricultural and natural habitat landscapes. This study uses InVEST's pollination model to simulate spatial indices of bee suitability based on the resource requirements and flight behaviour of wild bees and to predict the contribution of their abundance to crop yield indices.

The pollution and greenhouse gas emissions costs to the natural capital include water and air pollutants, solid wastes, and whole-life-cycle greenhouse gas emissions.

Water pollutants (nitrate, phosphate, pesticides): the coefficient method is used to calculate the material mass of water pollutant emissions. The emission coefficients for crop plantation are taken from literature averages (Table 4.3).

Atmospheric pollutants (ammonia nitrogen, nitrous oxide, nitrous oxide, nitrogen oxides, methane, pesticides): the coefficient method was used to account for the physical mass of air pollutant emissions based on emission factors reported in the literature for different types of plantations, as well as relevant quantitative values

4 http://www.chinacarbon.info/ 2020 carbon market price

obtained from field surveys. Emission factors for crop plantation were taken from the literature (Table 4.3).

Greenhouse gases: This study used life cycle assessment (LCA) method to account for the total life-cycle greenhouse gas emissions across the value chain, including carbon dioxide, methane and nitrous oxide emissions (Table 4.3).

Economic costs. In this study, different types of pollutants were converted into standard air or water pollutant substance equivalents. Then the economic value of the pollutants was accounted for in accordance with the provisions of the Approved Environmental Protection Tax Collection Standards of Yunnan Province to quantify the environmental costs of the pollutants[5]. Greenhouse gases were accounted for at a standard rate of 28.6 Yuan/t CO_2 equivalent (4 US$40/t CO_2 equivalent). In the sensitivity typology, the cost of greenhouse gases was accounted for at a social cost of carbon (SCC) of US$40/t C or 70.36 yuan/t CO_2 equivalent.

4.2.3 Produced capital assessment

Assessment of produced capital covers the benefits (crops produced) and costs (farming inputs/outputs) of agricultural production. Their net value (i.e. benefits minus costs) are numerically equivalent to the number of provisioning ecosystem services calculated by the residual value method. **Crop provisioning services** measure the contribution of ecosystems to the growth of crops (Table 4.3).

4.2.4 Human capital assessment

Assessment of human capital includes the labour benefits and health costs of agricultural production.

Quantity and salary of labour force: the quantity of labour is represented by the number of people involved in the labour force. The labour force is assumed to increase proportionally with the size of agriculture and labour force wages are also assumed to grow with the overall wage level of the country. Based on the size of different agricultural categories under different scenarios and the current labour force of different agricultural categories collected in the research, the future labour force required for different agricultural categories is projected.

5 The Approved Environmental Protection Tax Collection Standards of Yunnan Province does not specify what this price for each pollutant stand for, but the authors understand it to be the cost of the direct ecological impact of pollutant discharges, not covering its effects on human health, etc.

Occupational exposure: This study estimates the health effects of agricultural chemicals on agricultural practitioners through exposure after they enter the soil and diffuse into the environment. The primary consideration is the health effects of pesticides used in agricultural production on farmers in the farming industry through soil exposure, measured as lifetime theoretical maximum contributions (LTMCs) of chemicals and translated into human health damage factors (CFs). Occupational exposure under different scenarios is estimated based on current pesticide use for different crop types, future crop mix and pesticide use under different scenarios (Table 4.3).

Atmospheric pollution exposure: atmospheric exposure to pesticides and fertilisers is calculated from the use of pesticides and fertilisers (collected in the research data) and their coefficient of entry into the atmosphere. This study will use the ReCiPe method integrated into the Simapro software to calculate health impacts and use the health loss adjustment year (DALY) to measure the health risk characterisation factor (CF). Health impacts will be predicted under different scenarios based on the amounts of pesticides and fertilizers used (Table 4.3).

Downstream water exposure: exposure to pesticides and fertilisers in water bodies is calculated from the use of pesticides and fertilisers (collected in the research data) and the factor by which they enter the water body. Health impacts were calculated using the ReCiPe method integrated into the Simapro software. Health risk characterisation factors (CF) were calculated using the basis of the health loss adjustment year (DALY). Health impacts were predicted for different scenarios based on the amounts of pesticides and fertilizers used (Table 4.3).

Consumption of agricultural products: the health impacts associated with the consumption of agricultural products are calculated based on the residues of pesticides and other harmful substances in agricultural products, calculated through the "intake" of agri-food products, and the health risk characterisation factor (CF) is calculated based on the health loss adjustment year (DALY).

The economic value lost due to different health losses is estimated based on the health risk characterisation factor (CF) and the value of statistical life expectancy (VSL).

Table 4.3 Quantitative assessment methodology

	Category assessed	Material Quantity Assessment Method	Value Assessment Method
Natural Capital - Ecosystem Service Benefits	Water provisioning	The InVEST Fisheries model was used to estimate the relative contribution of water from different parts of the landscape and provide an analysis of how changes in land use patterns affect annual surface water production.	The economic value of water conservation services was calculated by multiplying the annual surface water production by the local water price.
	Water purification	Estimation using the InVEST model's water quality purification module. The model uses the principle of mass conservation to simulate the spatial migration of nutrients, providing analysis of the nutrient retention capacity of different land cover types for nitrogen and phosphorus, as well as the migration process and patterns.	It is estimated through the corresponding treatment cost of nitrogen and phosphorus.
	Soil retention	Soil conservation service is evaluated using the InVEST sediment delivery ratio model, which estimates the annual soil loss and sediment delivery rates spatially. Based on this, it can be determined how much of the beneficial elements in the soil (nitrogen and phosphorus) can be prevented from being lost through soil conservation practices.	The economic value of soil erosion control is then calculated by combining the prices of nitrogen and phosphorus fertilizers.
	Pollination	The InVEST pollination model was used to simulate the spatial suitability index of bees based on the resource requirements and flight behaviour of wild bees, and to predict their contribution to crop yield indices based on their abundance.	/
	Carbon sequestration	The InVEST Carbon Storage model is used to estimate the carbon sequestration of the four main carbon pools (aboveground biomass,	The economic value of carbon sequestration service is calculated according to the standard of 28.6 yuan per

		belowground biomass, soil, and dead organic matter) under different land uses.	ton of carbon dioxide equivalent (in the sensitivity analysis, greenhouse gas costs are calculated based on the social cost of 40 US dollars per ton of carbon)[6].
Natural Capital - Pollution and Greenhouse Gas Emissions Costs	Water pollutants (Nitrate, Phosphate, Pesticides)	The material quantity of water pollutants is calculated using the coefficient method. The emission coefficients are taken from literature averages.	Different types of pollutants are converted into standard water pollutant material equivalents, and their environmental costs are quantified in accordance with the "Heilongjiang Province Environmental Protection Tax Collection and Levying Standards," to quantify the environmental costs of pollutants.
	Air pollutants (Ammonia Nitrogen, Nitrous Oxide, Nitric Oxide, Nitrogen Dioxide, Methane, Pesticides)	Based on emission factors reported in the literature for different types of agriculture as well as relevant quantitative values obtained from field surveys, the coefficient method is used to calculate the amount of atmospheric pollutants emitted. The emission coefficients are obtained from literature averages.	Different types of pollutants are converted into standard atmospheric pollutant substance equivalents, and their environmental costs are quantified based on the "Heilongjiang Province Environmental Protection Tax Levying Standard." The economic value of greenhouse gases is calculated according to a standard of 28.6 yuan/ton of carbon dioxide equivalent (in the sensitivity analysis, the social cost of greenhouse

6 Wang Y., et al. 2022. Measurement of China's provincial social cost of carbon under the integrated socioeconomic-climate framework. Journal of Environmental Management, 321:115993. doi.org/10.1016/j.jenvman.2022.115993

			gases is calculated based on a standard of 40 US dollars/ton of carbon dioxide equivalent).
	Life Cycle Greenhouse Gas Emissions (Carbon dioxide, methane, and nitrous oxide).	Life Cycle Assessment (LCA) is used to calculate the greenhouse gas emissions throughout the entire value chain.	The greenhouse gases are quantified based on the standard of 28.6 yuan per ton of carbon dioxide equivalent. In the sensitivity analysis, the cost of greenhouse gases is calculated based on the social cost of 40 US dollars per ton of carbon.
Produced capital – crop benefits	Crops (paddy rice, maize, and soybean)	Field research was conducted to determine the yield of various agricultural products.	Agricultural product yield multiplied by its market price.
Produced capital – costs	Agricultural Inputs (Energy, Fuel, Fertilizer, and Pesticides)	Field research was conducted to determine the yield of various agricultural inputs.	Agricultural input multiplied by its market price.
Human capital – labour benefit	Labour quantity	The number of labour is represented by the number of people participating.	Value reflected by the wage levels.

Human capital – health costs	Occupational exposure (taking into account the health impacts on farmers in the planting industry through soil contact with pesticides used in agricultural production).	Calculating the chemical's lifetime theoretical maximum contribution (LTMCs) [7] and converting it into a human health damage factor (CF) [8], and using Disability Adjusted Life Years (DALYs) [9] to represent health (life) loss.	The calculation is done by multiplying the Disability-Adjusted Life Years (DALYs) by the Value of Statistical Life (VSL)[10].
	Exposure to atmospheric pollutants (exposure to fertilizers and pesticides in the atmosphere)	The exposure to atmospheric pollutants from the use of pesticides and fertilizers is calculated based on their usage data (collected during the survey) and their coefficients for entering the atmosphere. The ReCiPe[11] method integrated in the Simapro software is used to calculate health impacts, and the health loss-adjusted years (DALYs) are used to characterize the health risk characterization factor (CF).	Using the Value of a Statistical Life (VSL) multiplied by the Disability-Adjusted Life Year (DALY) to calculate the health impact.
	Downstream water exposure (rivers, lakes, etc.) to pesticides and	It is calculated based on the usage data of pesticides and fertilizers (collected during the survey) and their coefficients for entering water bodies. The health impact is calculated using the ReCiPe method	The statistical value of a life (VSL) is multiplied by DALYs to calculate the economic value of health losses.

7 The theoretical maximum contribution of chemical lifetime (LTMCs) refers to the time it takes for a chemical substance to degrade into its metabolites in the environment. LTMCs of pesticides are computed from human major exposure routes at maximum legal exposures, which include residential soil, drinking water, and agricultural foods (Li, 2018).
8 The human health impact factor (CF) refers to the relative strength of the damage caused by a unit of chemical substance to the human body under specific exposure pathways, represented by Disability-Adjusted Life Years (DALYs).
9 DALYs are used to assess the impact of diseases and injuries on human health (life expectancy). It is the sum of the years of life lost due to premature death and the years of life lived with disability caused by epidemics or health conditions.
10 The Value of Statistical Life (VSL) refers to the willingness of people to pay to reduce the risk of adverse health effects, such as premature death, resulting from environmental pollution.
11 ReCiPe is a life cycle impact assessment method which comprises harmonized category indicators at the midpoint and the endpoint level. In this study, ReCiPe method is deployed to calculate the endpoint health risk of atmospheric and downstream water pollution exposures, which is also called characterization factor measured in DALY (Goedkoop et al., 2009).

	fertilizers used in agricultural production.	integrated in SimaPro software, and the health risk characterization factor (CF) is represented by disability-adjusted life years (DALYs).	
	Agricultural consumption (residual pesticides and other harmful substances)	Amount of intake through food consumption is calculated, and the risk characterization factor (CF) is expressed using the disability-adjusted life year (DALY)	The value of statistical life (VSL) is multiplied by DALY to calculate the health impact.

4.2.5 Social capital assessment

The women empowerment aspect mainly includes the female labour force in the agri-food system and their wages. Based on the above data on the current female workforce in the agri-food system in Heilongjiang Province obtained from the research and based on the expected development of the agri-food system under different scenarios, we can project the number and distribution of the female workforce in different agricultural categories. Income of the female labour force under different scenarios is projected based on historical data of agricultural wage of the country.

The social mechanism refers mainly to agricultural cooperatives. Based on data on rural cooperatives in different sectors, we project that the number of cooperatives in paddy rice, maize, and soybean plantation will grow in accordance with production demand. ****

4.2.6 Analysis framework

The following figure shows the main content and the process of the analysis, as well as the proposed methods to be used.

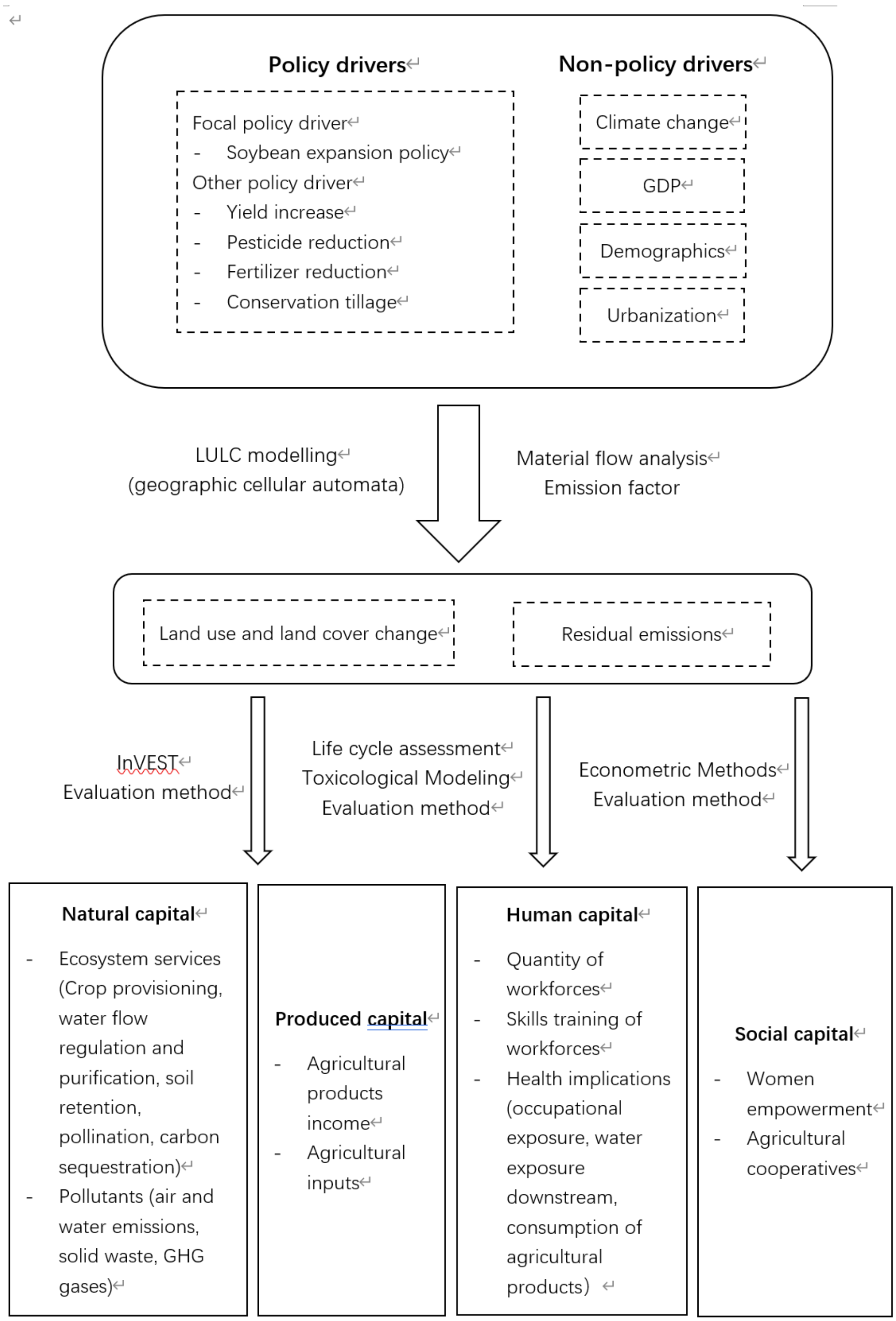

Figure 4.1 Technical framework of the study

5. Land-use and land-cover modelling

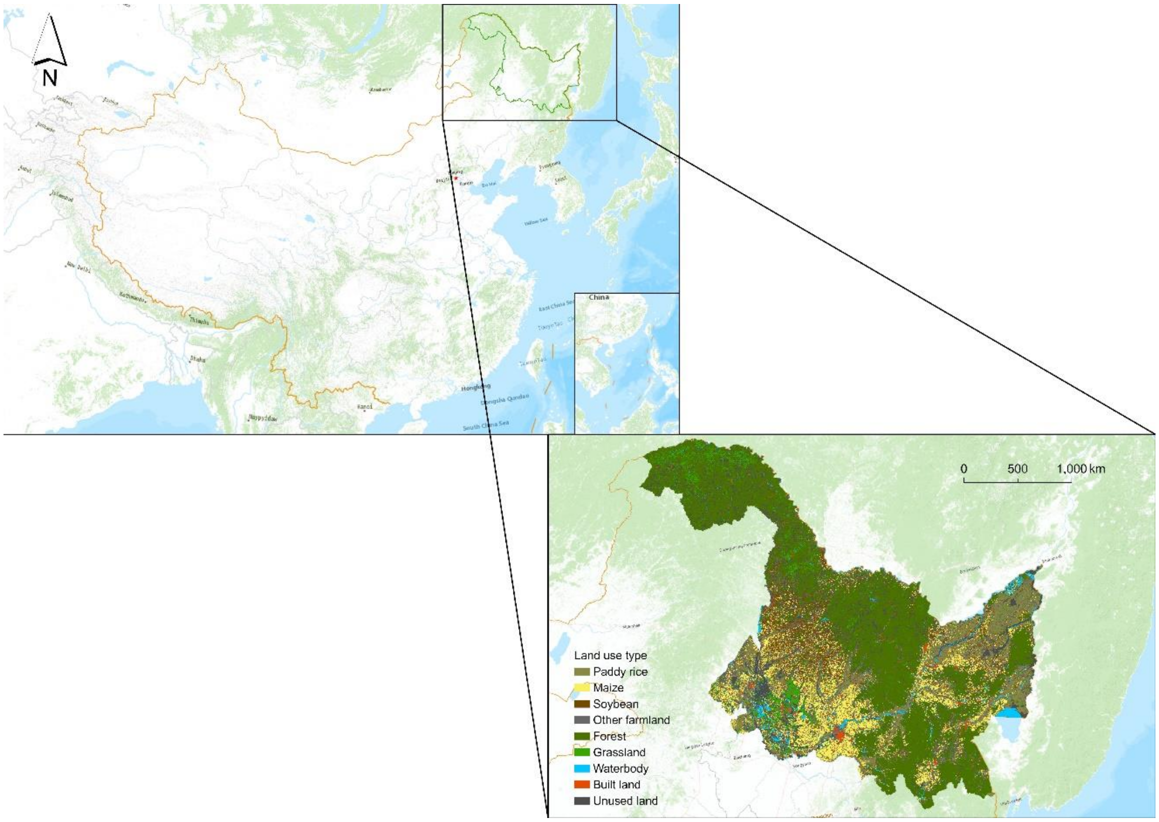

Figure 5.1 Land-use and cover conditions in Heilongjiang Province in 2022

This study takes the land use and land cover status of Heilongjiang Province in 2022 (Figure 5.1) as the starting point, and simulates future changes of the main crops, namely paddy rice, maize, and soybean, by overlaying socioeconomic and natural driving forces derived from historical trends.

The decision to focus exclusively on simulating changes in the land use types of paddy rice, maize, and soybeans in the future scenarios while excluding other land types in these simulations is justified by several key considerations. Firstly, these three land use types represent the primary components of Heilongjiang's agricultural landscape (accounting for over 95% of the planted area of grain crops in Heilongjiang Province) and have the most substantial influence on the nation's food security, economic well-being, and environmental sustainability. By concentrating on these crucial land use categories, the analysis can provide a more targeted and actionable assessment of the tradeoffs and impacts associated with changes in agricultural practices.

Secondly, the selected land use types are inherently interrelated and often compete for the same arable land resources. Understanding how alterations in policy and climate scenarios affect the allocation of land among these specific crops provides valuable insights into the intricate balance between food production, economic considerations, and environmental consequences. By narrowing the focus to these three land use types, the analysis can better capture the nuances of trade-offs and synergies that are vital for informed decision-making in China's agricultural sector.

Lastly, while excluding other land types from the simulations, we acknowledge their importance and potential implications in ecosystem services, biodiversity conservation, and other environmental factors. Therefore, the ensuing assessment of various capitals will comprehensively consider the broader landscape and its ecological functions for an overall evaluation. However, for the explicit purpose of assessing the tradeoffs generated by changes among paddy rice, maize, and soybean, the chosen approach allows for a more focused and in-depth examination of the critical factors driving land use decisions and their consequences for China's agri-food system.

Over the course of the projected future, the land use simulation results reveal significant fluctuations in cultivated areas for paddy rice, maize, and soybeans (Table 5.1), with variations influenced by different climate scenarios (RCP 4.5 and RCP 8.5) and policy pathways (BAU, Grain Priority, and Soybean Priority). These changes highlight the dynamic nature of agricultural land use in response to evolving environmental conditions and policy directions. It is noteworthy that there are some changes in the total cultivated land of the three main crops, which are mainly contributed by climate change induced non-arable land converting to arable land, such as saline land or land in extreme cold weather conditions.

Table 5.1 Cultivated area (km^2) of main crops in Heilongjiang Province

Time	Climate scenario	Policy pathway	Paddy rice	Maize	Soybean
2022	/	/	51069	52454	29294
2025	RCP4.5	BAU	38501	56421	31462
2025	RCP 4.5	Grain priority	38895	56999	31462
2025	RCP 4.5	Soybean priority	35087	37614	54369
2025	RCP 8.5	BAU	38501	56421	31462
2025	RCP 8.5	Grain priority	38895	56999	31462
2025	RCP 8.5	Soybean priority	35087	37614	54369
2035	RCP 4.5	BAU	38314	56147	33521
2035	RCP 4.5	Grain priority	39682	58155	33521
2035	RCP 4.5	Soybean priority	28261	488	99694

2035	RCP 8.5	BAU	38314	56147	33521
2035	RCP 8.5	Grain priority	39682	58155	33521
2035	RCP 8.5	Soybean priority	28261	345	99837
2050	RCP 4.5	BAU	38007	55698	33521
2050	RCP 4.5	Grain priority	40743	59174	33521
2050	RCP 4.5	Soybean priority	28261	523	99659
2050	RCP 8.5	BAU	38007	55698	33521
2050	RCP 8.5	Grain priority	40743	59174	33521
2050	RCP 8.5	Soybean priority	28261	341	99841

A graphical representation of the land use patterns under the 2050-RCP 4.5 scenarios is drawn to better depict the changes amongst the three crop types (Figure 5.2). It is clear that under the Soybean priority scenario, soybean expansion is mainly driven by a reduction in maize areas.

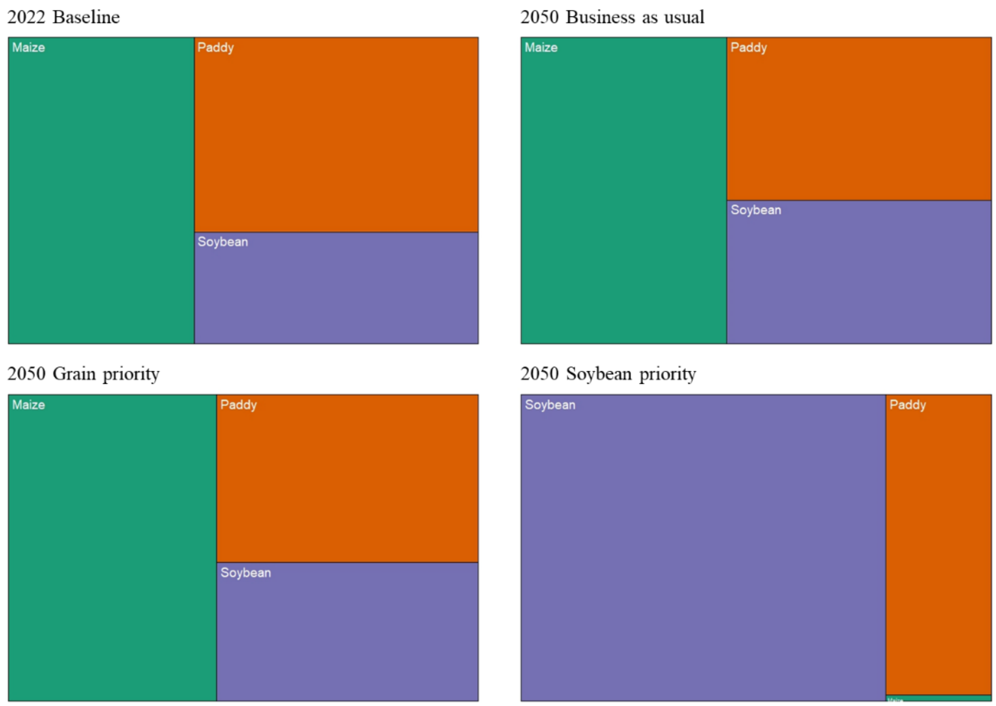

Figure 5.2 Land use patterns of the three development scenarios (BAU, Soybean priority, and Grain priority) under the 2050-RCP 4.5 context.

In 2022, under baseline conditions, paddy rice cultivation covered 51,069 km², maize 52,454 km², and soybeans 29,294 km². By 2025, in the RCP 4.5 scenario with the Business as Usual (BAU) policy pathway, paddy rice and maize areas decreased by approximately 24% and 7%, respectively, while soybeans remained relatively stable, decreasing by only 7%. Conversely, under the Grain Priority policy pathway, paddy rice and maize areas increased by about 6%, while soybeans remained steady. In contrast, the Soybean Priority policy pathway resulted in a substantial 86% increase in soybean cultivation, accompanied by significant reductions in paddy rice and maize areas.

Moving to 2035, under the RCP 4.5 scenario, paddy rice and maize areas continued to decrease across all policy pathways, with reductions of approximately 19% and 15%, respectively, while soybeans exhibited a remarkable 216% increase under the Soybean Priority pathway. In the RCP 8.5 scenario, these trends persisted, with some variations, particularly in the Soybean Priority pathway, where soybean cultivation expanded by 315%.

By 2050, the trends remained consistent. The Grain Priority pathway consistently promoted larger areas of paddy rice and maize compared to the BAU pathway, with increases of about 7% and 8%, respectively, while the Soybean Priority pathway consistently prioritized soybean cultivation, resulting in an 257% increase in soybean area.

6. Assessment of natural capital

6.1 Natural capital: Ecosystem service benefits

6.1.1 Water provisioning

The provision of fresh water is largely related to human survival and ecological stability and has an impact on the available water quantity, soil distribution, vegetation growth, and distribution of the watershed. The analysis of water provisioning services in Heilongjiang Province reveals considerable changes in total values over the years. This assessment not only sheds light on the evolving dynamics of water provisioning but also helps discern the predominant drivers of change, whether it be climate scenarios or agricultural development choices.

The study found that the choice of agricultural development pathways significantly influenced water provisioning. Soybean Priority (SP) consistently outperformed Grain Priority (GP) and Business as Usual (BAU) scenarios in all years, highlighting the importance of prioritizing soybean production for enhancing water resources. While climate scenarios had some impact, the primary driver of change was agricultural development choices, emphasizing the role of agricultural practices and policies in water resource availability.

Specifically, in the baseline year of 2022, the total water provisioning services were measured at 291,318.67 million yuan[12]. This serves as a reference point for evaluating changes in subsequent years. There is a considerable drop of the total value projected for the future timelines, which results from a combination of land use change, precipitation, and evapotranspiration. When comparing the years 2025, 2035, and 2050, it becomes evident that the choice of agricultural development pathway, represented by BAU (Business as Usual), GP (Grain Priority), and SP (Soybean Priority), plays a pivotal role in determining water provisioning outcomes (Figure 6.1).

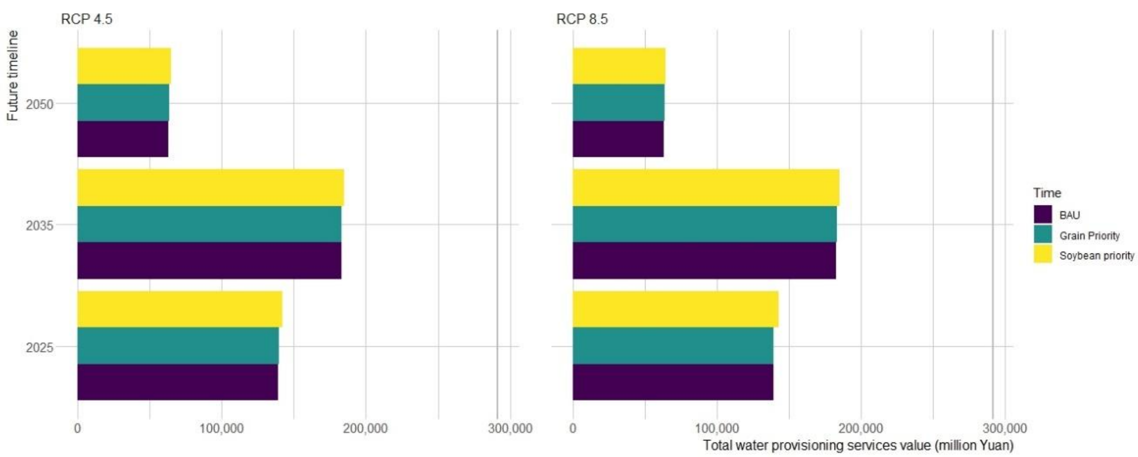

Figure 6.1 Value of water provisioning services (million Yuan) in Heilongjiang Province

It is worth noting that while the total change in water provisioning services is substantial in absolute figures, the relative change in percentages remains relatively small, reaching a maximum of 3%. Climate changes primarily account for the temporal differences observed over the years, whereas agricultural choices mainly explain variations between scenarios.

In 2025, under the RCP 45 climate pathway, SP outperformed GP and BAU, providing approximately 2.9% and 2.2% more water provisioning services, respectively. This suggests that prioritizing soybean production (SP) enhances water provisioning capabilities compared to grain-focused strategies (GP and BAU). In 2035, the differences between the pathways persisted. The SP scenario continued to outperform GP and BAU, providing

[12] This report presents monetary values in 2022-equivalent amounts, future values are adjusted using an annual CPI of 1.7%.

approximately 1.2% and 1.0% more water provisioning services, respectively. This indicates the sustained advantage of soybean-focused agricultural development in terms of water provisioning. In 2050, the trend remained consistent, with SP delivering approximately 1.9% and 1.3% more water provisioning services, respectively, compared to GP and BAU (Figure 6.1).

In conclusion, the analysis underscores the critical role of agricultural development pathways in influencing water provisioning services. The SP (Soybean Priority) pathway consistently outperformed the GP (Grain Priority) and BAU (Business as Usual) pathways in all years, with percentage differences ranging from 1.0% to 2.9%. This suggests that prioritizing soybean production, while increasing overall soybean production, enhances the capacity to provide essential water resources for various needs. In summary, the analysis indicates that while climate scenarios do have some impact on water provisioning, the primary driver of change in water provisioning services over the years in Heilongjiang Province appears to be agricultural development choices. The substantial fluctuations in water provisioning values are more closely tied to the agricultural development pathways, emphasizing the importance of agricultural practices and policies in determining water resource availability in the region.

6.1.2 Water purification

The water purification function of an ecosystem is the absorption, retention, decomposition, and transformation of nutrients such as N and P in the region by each constituent element of the ecosystem. We use the ability to transfer nutrients (N and P) to express the water purification function, which translates to the water purification capacity of the region.

The analysis of total purification services over time reveals some noteworthy trends—while the total purification services for the three main crops gradually decline over the years, they display very little differences within each year across climate and development pathways.

Specifically, in the baseline year of 2022, the total purification services were calculated at 24.26 million Yuan. As we move forward to 2025 under different climate pathways, slight fluctuations in these services are observed, but no significant changes are evident. For instance, under RCP 4.5-BAU, purification services were 24.39 million Yuan, closely matched by RCP 4.5-GP at 24.40 million Yuan. However, the SP scenario, also under RCP 4.5, recorded slightly higher purification services at 24.52 million Yuan (Figure 6.2).

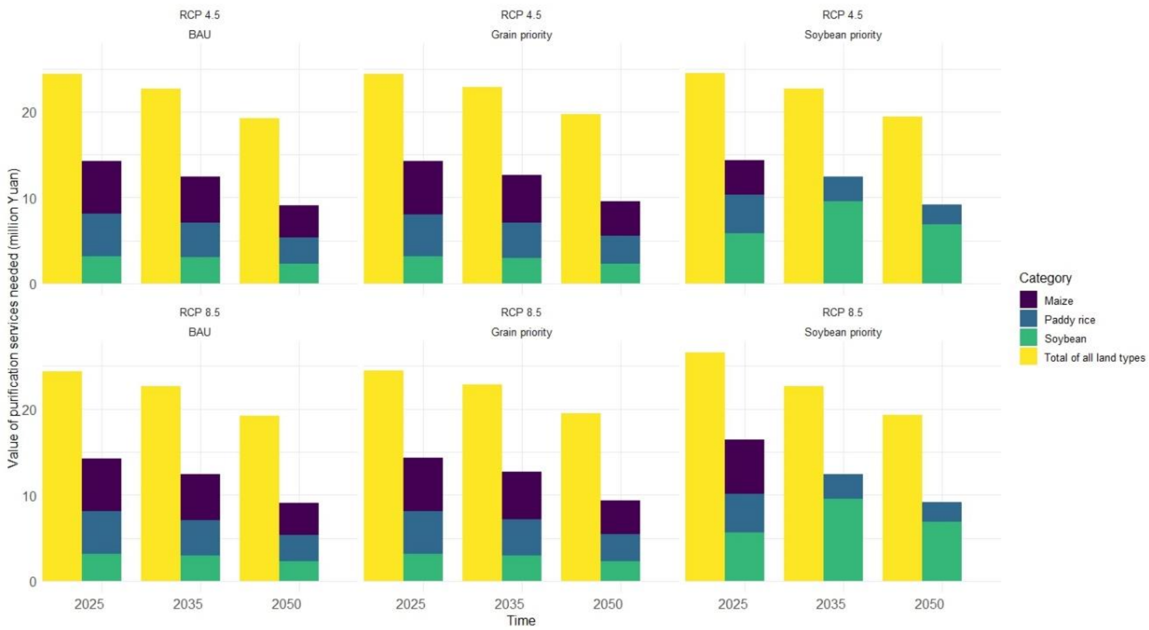

Figure 6.2 Water purification services (million Yuan) in Heilongjiang Province.

Jumping ahead to 2035, we continue to observe minor variations in purification services. For instance, under RCP 4.5-BAU, these services amount to 22.65 million Yuan, while under RCP 8.5-GP, they increase to 22.88 million Yuan. Interestingly, the SP pathway under RCP 8.5 records the highest purification services at 26.58 million Yuan. Finally, in 2050, there is a more pronounced reduction in purification services across the board, with RCP 4.5-GP having the highest at 19.70 million Yuan. The changes observed between scenarios are minimal. However, we see a slight decrease in the total services from 2025 to 2050, mainly due to the changing climate. (Figure 6.2).

Delving into the contributions of the three main crops – paddy rice, maize, and soybean – to purification services, it's clear that these crops play pivotal roles in determining the results. Paddy rice and maize consistently emerge as the leading contributors to purification services among the three crops in the BAU and GP scenarios, maintaining a stable performance over various years. On the other hand, soybean's contribution remains relatively lower compared to paddy rice and maize, except in the SP scenarios where it rises to the highest contributor.

6.1.3 Carbon sequestration

Ecosystems regulate the global climate by absorbing gases such as CO_2, and storing the absorbed carbon in biological organisms, dead organic matter, and soil.

In the context of Heilongjiang Province's unique agricultural dynamics and the specific focus on changing crop cultivation patterns, it is essential to adapt the traditional approach of assessing carbon sequestration services. While many regions typically evaluate the carbon sequestration potential of all land use types, Heilongjiang Province presents a distinctive scenario. Here, the primary concern lies in the trade-offs resulting from shifts in the cultivation of maize, paddy rice, and soybean. The annual nature of crop growth in this region means that any carbon sequestered during one season will eventually be released back into the atmosphere at the end of that season. This cyclical pattern effectively negates the long-term carbon sequestration potential associated with these crops. Therefore, the focus shifts from merely assessing carbon sequestration services to evaluating the entire life-cycle greenhouse gas emissions and captures, including the carbon sinks.

This shift in perspective aligns with the dynamic nature of Heilongjiang's agricultural landscape, where crops are cultivated on an annual basis. By considering the entire life cycle, encompassing emissions during crop growth, as well as subsequent release and potential recapture in the ecosystem, we gain a more comprehensive understanding of the net greenhouse gas implications of changing crop cultivation patterns. This approach accounts for the complex interplay of emissions and captures associated with these crops and provides a holistic view of their environmental impact. In essence, it recognizes that while carbon may not be permanently sequestered, the overall greenhouse gas dynamics remain a crucial aspect of sustainable land use management in Heilongjiang Province.

The whole life-cycle GHG analysis will be covered in section 6.2.

6.1.4 Soil retention

Soil erosion control (conservation) service is an important aspect of ecosystem services, which provides an important foundation for soil formation, vegetation growth, and water provision, and also provides ecological security and system services.

The total soil retention services encompass contributions from all land use types, and the three main crops contribute little to the total soil retention services. From 2025 to 2050, values fluctuate across pathways and climate scenarios with no discernible trends.

Specifically, in 2022, the total value amount to 7,485.03 million Yuan, with the three main crops contributing approximately 409.23 million Yuan, accounting for roughly 5.47% of the total. As we advance to 2025, the values undergo fluctuations across different pathways. Under the RCP 4.5 climate scenario, the services decrease, ranging from 7,348.48 to 7,350.18 million Yuan, with the GP pathway showing a slightly higher value. Meanwhile, under the RCP 8.5 scenario, the values again range from 7,349.27 to 7,353.56 million Yuan, with the SP pathway exhibiting the highest value. By 2035, the values remain relatively stable, ranging from 7,389.06 to 7,436.58 million Yuan across different pathways.

As we move to 2050, the fluctuations continue, with the values ranging from 7,289.66 to 7,334.38 million Yuan under RCP 8.5, while under RCP 4.5, they range from 7,289.92 to 7,307.46 million Yuan. Throughout this period, the contributions of the three main crops to soil retention services remain relatively low, indicating that soil retention services are primarily influenced by other land use types and/or factors (Figure 6.3).

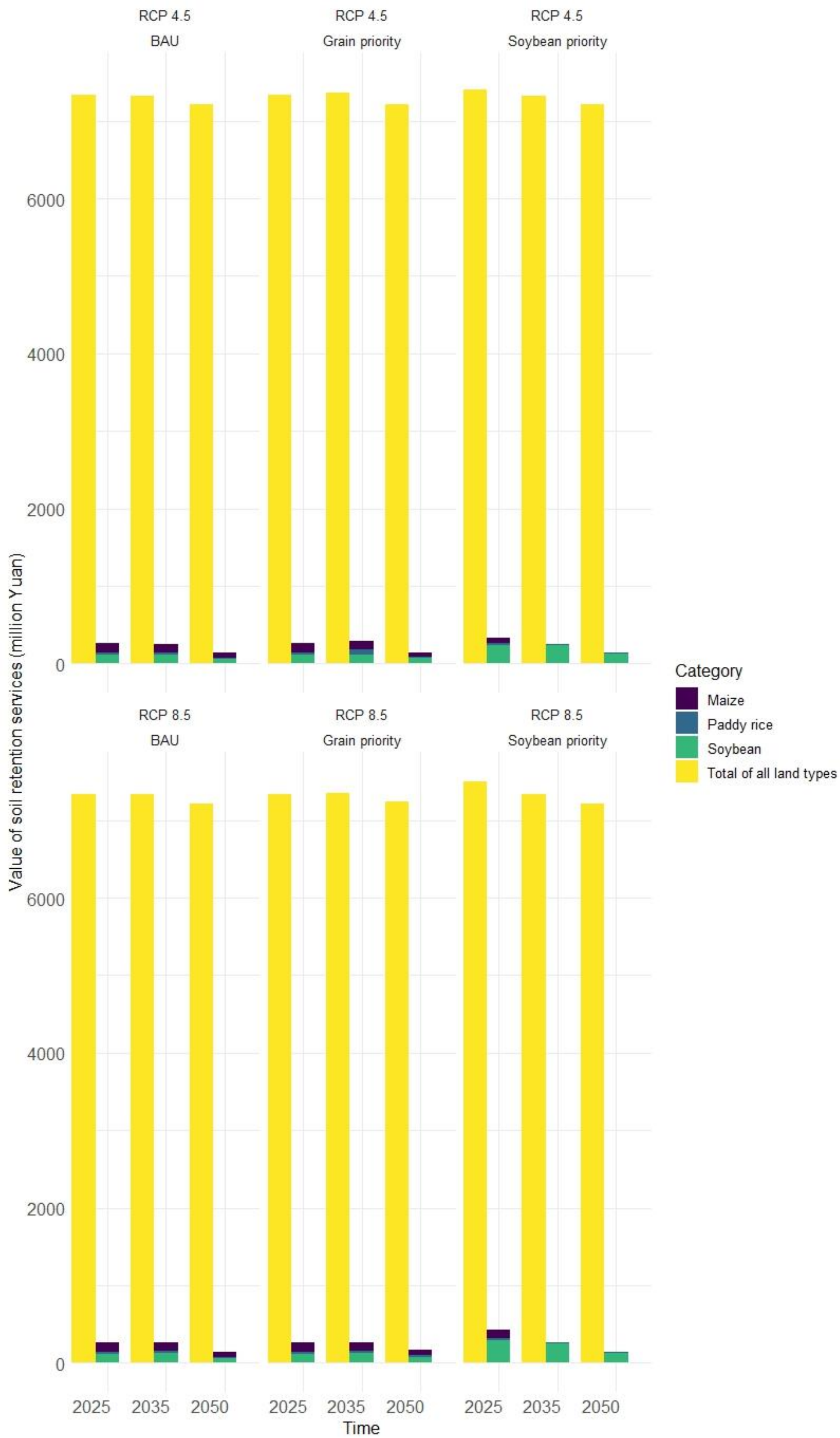

Figure 6.3 Total soil retention services (million Yuan) in Heilongjiang Province

Focusing solely on soil retention services contributed by the three main crops—paddy rice, maize, and soybean—provides insights into changes caused by the soybean expansion practices. The variations in soil retention services within the same year across different development pathways are more pronounced than variations across climate scenarios. In 2022, the three main crops collectively provide soil retention services valued at 409.23 million Yuan. By 2025, the values fluctuate across pathways. Under the RCP 4.5 climate scenario, the services decrease to 272.68 (BAU), 274.38 (GP), and 351.43 (SP) million Yuan, indicating variations within different development pathways. Under the RCP 8.5 scenario, similar trends are observed, with values ranging from 273.47 to 277.76 million Yuan. The SP scenario performs better than the GP scenario in terms of total soil retention services values. Soybean is a key contributor to the improved performance of the SP scenario in that specific year (Figure 6.3).

In 2035, the services continue to show fluctuations. Under RCP 4.5, values range from 313.26 to 360.78 million Yuan, reflecting differences across development pathways. Under RCP 8.5, values fluctuate from 325.63 to 333.98 million Yuan. Moving to 2050, the values continue to fluctuate, with variations ranging from 213.86 to 258.59 million Yuan under RCP 8.5, and from 214.12 to 231.66 million Yuan under RCP 4.5. The GP scenarios outperforms the other two scenarios in 2035 and 2050, while BAU had the lowest values (Figure 6.3).

6.1.5 Pollination

The analysis of pollination services reveals a relatively stable trend over the years 2022 to 2050. There are only slight variations in the values, and these changes do not follow a discernible pattern or trend. Regardless of the climate pathways considered, the pollination services remain consistent within the same year. This consistency suggests that pollination services are not significantly influenced by changes in climate scenarios.

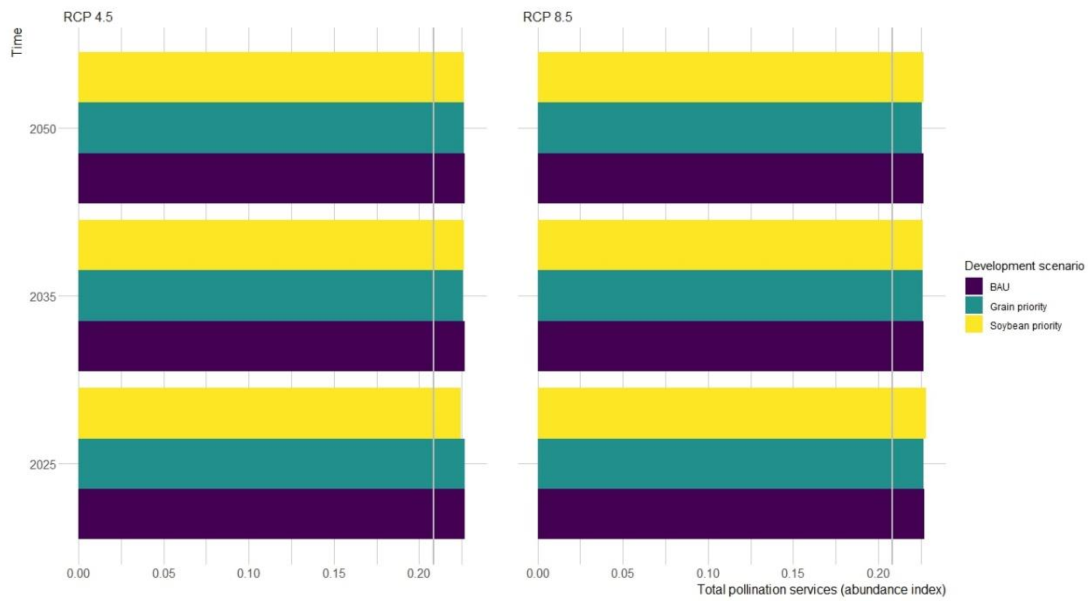

Figure 6.4 Pollinator abundance in Heilongjiang Province.

Furthermore, when examining the impact of agricultural development scenarios, the data also indicates minimal changes in pollination services over time. The variations observed in pollination services across different agricultural development pathways are relatively small and do not demonstrate a clear pattern influenced by these scenarios.

Overall, the analysis of pollination services suggests that they are relatively stable and not significantly affected by changes in either climate pathways or agricultural development scenarios.

6.2 Natural Capital: Pollution and Greenhouse Gas Emissions Costs

The types of residual pollutants in this section include water pollutants from maize, rice, and soybean cultivation (nitrate[13], phosphate, pesticides), air pollutants from maize, rice, and soybean cultivation (ammonia nitrogen, nitrous oxide, nitric oxide, nitrogen dioxide, and pesticides), solid waste from unused straw (as there are no unused straw, solid waste is not calculated), and whole-life-cycle greenhouse gas emissions (carbon dioxide, methane, nitrous oxide and other greenhouse gases emissions deputed in IPCC 5th report). Analysis is carried out with respect to different crop categories. Detailed methodology can be found in the Data and Methodology Report[14].

13 Nitrate is classified as total nitrogen and phosphate as total phosphorus for uniform accounting.
14 https://teebweb.org/wp-content/uploads/2022/05/Data-and-Methodology-Report_Final.pdf

6.2.1 Water pollutants

Nitrate, phosphate and pesticides water emissions from maize, rice, and soybean cultivation are included in the analysis. As the discharges of water pollutants between the different climate scenarios (RCP4.5 and RCP8.5) and the discharge profiles are identical, only the results for RCP4.5 is shown in this section.

The total water pollutant emissions are shown in Table 6.1 and the changes are shown in Figure 6.5. In terms of pollutant types, nitrate emissions are the largest, followed by phosphate, while pesticide emissions are smaller. Looking at future scenarios, in the same year, for all pollutants, emissions in the SP scenario are lower than in BAU scenario, and emissions in the BAU scenario are lower than in GP scenario, but they are all lower than that in 2020 mainly due to the fertilizers and pesticides reduction in future years. Taking 2050 for instance, the nitrate emission in SP scenario is only 49.63% of that in BAU scenario, while GP scenario is 105.80% of that in BAU scenario. The main reasons include that the per unit fertilizer input in soybean plantation is much lower than that in grain plantation, so the corresponding nitrate emissions intensity is lower in soybean plantation. As in SP scenario the plantation area of soybean is much higher than in BAU and GP scenarios, while the plantation area of grain is much lower, the nitrate emissions in SP is lower than that in BAU and GP. However, the emissions of pesticides do not show the same trend since the pesticide emission intensities in different plantation categories vary not that much.

Table 6.1 Water pollutants emissions in agriculture plantation GP: grain priority, SP: soybean priority

Pollutants	**Unit**	**2022**	**BAU-2025**	**GP-2025**	**SP-2025**	**BAU-2035**	**GP-2035**	**SP-2035**	**BAU-2050**	**GP-2050**	**SP-2050**
Nitrate	kt	315.98	268.79	271.78	228.83	235.69	243.19	122.43	233.07	246.60	115.68
Phosphate	t	4847.83	3385.96	3421.54	3021.23	1931.48	1996.90	1220.88	1659.78	1766.67	1007.76
Pesticide	t	23.67	16.36	16.50	16.85	15.99	16.46	16.00	14.35	15.19	14.02

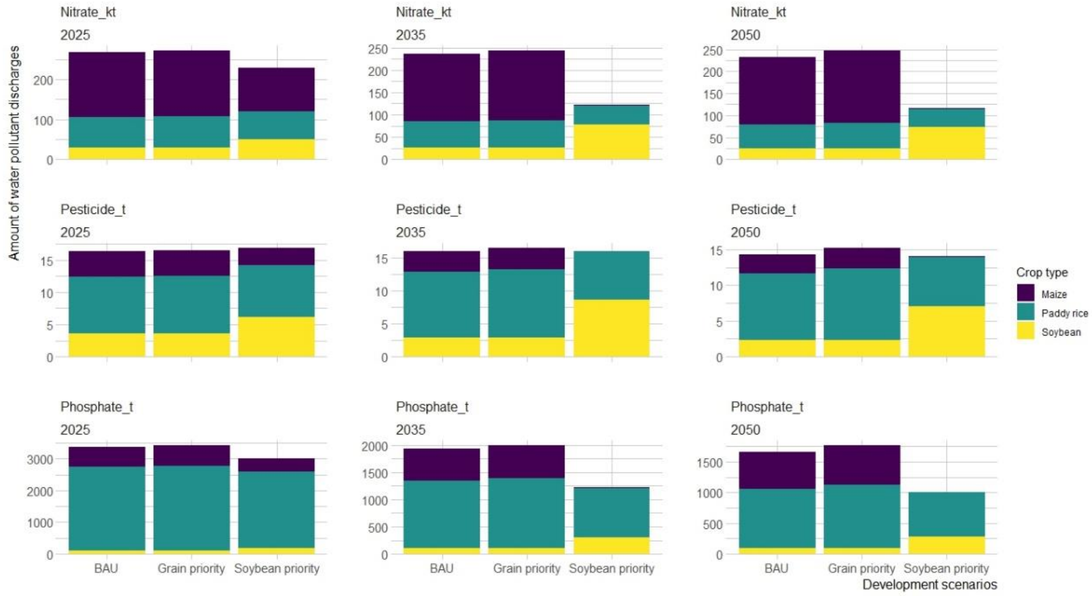

Figure 6.5 Pattern of water pollutants emissions in agriculture plantation

The economic costs of water pollutants are shown in Table 6.2, Table 6.3 and Fig. 6.6. As shown, the economic costs of water pollutants are mainly derived from nitrate, with lower economic costs for phosphate and pesticide water discharges. The economic cost of water pollutants is lower in the future scenario than in 2020, and the SP is smaller than the BAU scenario, and the BAU and GP scenarios have limited differences. In 2050, for example, the minimum economic cost is the SP scenario (129.92 million Yuan, 50.34% lower than the BAU scenario) and the maximum economic cost is the GP scenario (276.81million Yuan, 5.80% higher than the BAU scenario).

Table 6.2 Economic costs of major water pollutant discharges from agricultural plantation
GP: grain priority, SP: soybean priority

Pollutants	**Unit**	**2022**	**BAU-2025**	**GP-2025**	**SP-2025**	**BAU-2035**	**GP-2035**	**SP-2035**	**BAU-2050**	**GP-2050**	**SP-2050**
Nitrate	Million yuan	353.90	301.05	304.39	256.29	263.98	272.37	137.12	261.04	276.19	129.57
Phosphate	Million yuan	1.70	1.19	1.20	1.06	0.68	0.70	0.43	0.58	0.62	0.35
Pesticide	Million yuan	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00

Total	Million yuan	355.60	302.23	305.59	257.35	264.65	273.07	137.55	261.62	276.81	129.92

Table 6.3 Economic costs of major water pollutant discharges from agricultural plantation by crop categories GP: grain priority, SP: soybean priority

Water pollutants	Unit	2022	BAU-2025	GP-2025	SP-2025	BAU-2035	GP-2035	SP-2035	BAU-2050	GP-2050	SP-2050
Maize	Million yuan	183.89	181.83	184.28	121.60	168.47	174.50	1.46	172.18	182.93	1.62
Rice	Million yuan	136.98	88.56	89.47	80.71	67.05	69.45	49.46	61.72	66.17	45.90
Soybean	Million yuan	34.72	31.85	31.85	55.03	29.13	29.13	86.63	27.72	27.72	82.41
Total	Million yuan	355.60	302.23	305.59	257.35	264.65	273.07	137.55	261.62	276.81	129.92

Figure 6.6 Patterns of the economic costs of major water pollutant discharges from crop plantation

6.2.2 Atmospheric pollutants

The atmospheric pollutant emissions examined in this report include nitrous oxide (N_2O), ammonia (NH_3), nitric oxide (NO), nitrogen oxides (NOx), and pesticides. As there are no significant differences in emissions of atmospheric pollutants between the different climate scenarios (RCP4.5 and RCP8.5) and the emission profiles are similar, only the results for RCP4.5 is shown in the results.

The changes in total air pollutant emissions are shown in Table 6.4 and Figure 6.7. In terms of pollutant types, ammonia (NH_3), nitrous oxide (N_2O), nitric oxide (NO), and nitrogen oxide (NOx) emissions are higher, with NH_3 having the highest emissions and pesticides having smaller emissions. Looking at the different scenarios, for most pollutants, the SP has dramatically lower emissions than the BAU scenario and the BAU scenario has slight lower emissions than the pessimistic scenario. This is mainly due to the increasing plantation area of soybean and the decreasing plantation area of maize. As mentioned, the fertilizers application intensity and air pollutants emission intensity of soybean are much lower than that of maize. Therefore, the SP has considerably less air pollutants than BAU. As the plantation structure of the SP and GP has no significant differences, the air pollutants have limited variations. In the future years, the atmospheric pollutants emissions are lower for the same development scenario, mainly due to the improvement in fertilizers and pesticides usage efficiency and lower air pollutants emissions intensity.

Table 6.4 Characteristics of major atmospheric pollutant emissions in plantation GP: grain priority, SP: soybean priority

Pollutants	**Unit**	**2020**	**BAU-2025**	**GP-2025**	**SP-2025**	**BAU-2035**	**GP-2035**	**SP-2035**	**BAU-2050**	**GP-2050**	**SP-2050**
N_2O	kt	33.24	26.00	26.29	22.57	19.60	20.23	10.86	18.62	19.73	9.82
NH_3	kt	83.23	69.16	69.92	59.32	56.62	58.43	29.95	55.38	58.62	27.95
NO	kt	53.31	35.80	36.18	32.29	18.02	18.65	12.22	14.61	15.60	9.66
NO_X	kt	3.29	2.58	2.61	2.24	1.94	2.01	1.08	1.85	1.96	0.97
Pesticide	t	4.08	2.82	2.84	2.91	2.76	2.84	2.76	2.47	2.62	2.42

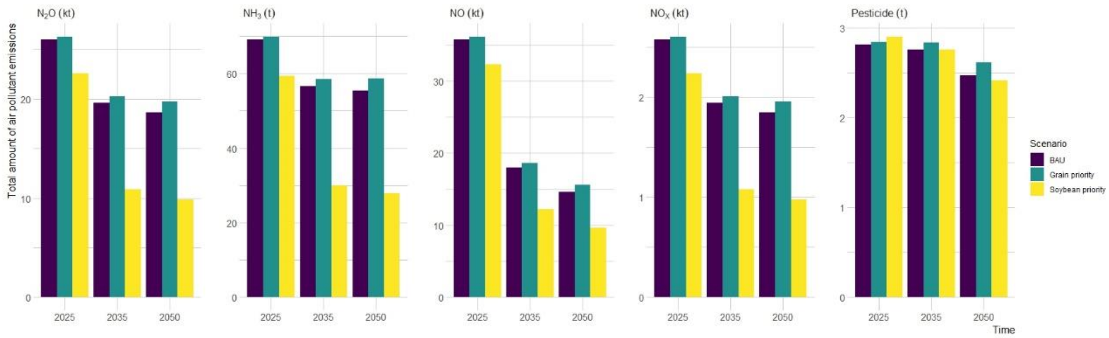

Figure 6.7 Patterns of major atmospheric pollutant emissions from agricultural plantation

In terms of economic costs (Table 6.5, Table 6.6 & Figure 6.8), the cost of air pollutants from the agricultural plantation is approximately 197.30 million yuan in 2020, but it will decrease in the future years. In the same year, the cost of air pollutants in SP is lower that than in BAU and GP, while BAU and GP have limited differences. For instance, in 2050, the air pollutants in SP are 55 million yuan, which is 46.50% lower than that in BAU (103.12 million yuan), and the air pollutants in GP is 109.33 million yuan, which is 6.02% higher than that in BAU. The economic cost of atmospheric pollutants is mainly derived from the emissions of ammonia, nitrous oxide, and nitrous oxide, and the economic cost of atmospheric emissions of pesticides is low.

Table 6.5 Economic costs of major atmospheric pollutant emissions from agricultural plantation

Pollutants	**Unit**	**2020**	**BAU-2025**	**GP-2025**	**SP-2025**	**BAU-2035**	**GP-2035**	**SP-2035**	**BAU-2050**	**GP-2050**	**SP-2050**
N_2O	Million yuan	37.89	29.65	29.97	25.73	22.34	23.06	12.38	21.22	22.49	11.19
NH_3	Million yuan	94.88	78.84	79.71	67.62	64.55	66.61	34.15	63.14	66.83	31.86
NO	Million yuan	60.77	40.82	41.24	36.81	20.55	21.26	13.93	16.66	17.78	11.02
NO_X	Million yuan	3.75	2.94	2.97	2.55	2.22	2.29	1.23	2.11	2.23	1.11
Pesticide	Million yuan	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Total	Million yuan	197.30	152.24	153.88	132.72	109.65	113.22	61.69	103.12	109.33	55.18

Table 6.6 Economic costs of major atmospheric pollutant emissions from agricultural plantation by crop category

Air pollutants	Unit	2022	BAU-2025	GP-2025	SP-2025	BAU-2035	GP-2035	SP-2035	BAU-2050	GP-2050	SP-2050
Maize	Million yuan	61.20	60.51	61.33	40.47	56.07	58.07	0.49	57.30	60.88	0.54
Rice	Million yuan	124.55	81.13	81.96	73.93	43.89	45.45	32.37	36.59	39.23	27.21
Soybean	Million yuan	11.56	10.60	10.60	18.32	9.70	9.70	28.83	9.23	9.23	27.43
Total	Million yuan	197.30	152.24	153.88	132.72	109.65	113.22	61.69	103.12	109.33	55.18

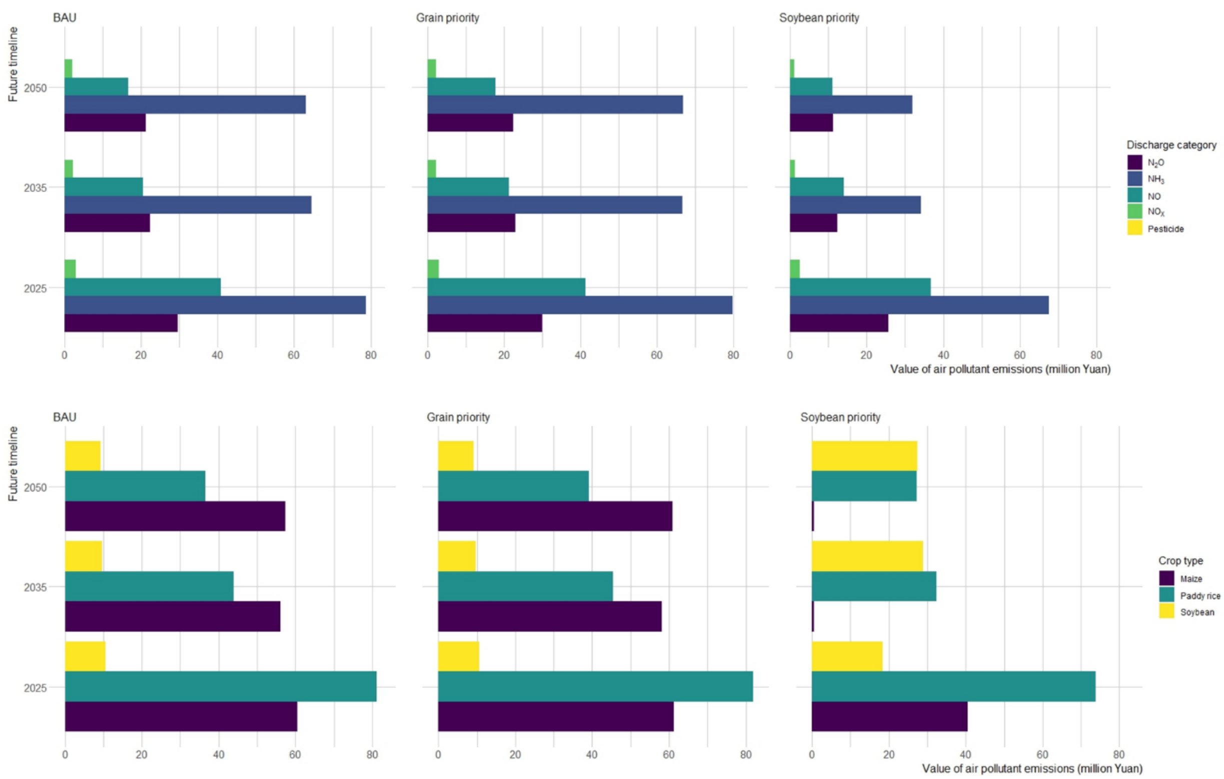

Figure 6.8 Economic costs of major atmospheric pollutant emissions in agricultural plantation

6.2.3 Life-cycle greenhouse gas emissions

This report accounts for the total life-cycle GHG emissions of agricultural plantation using a life cycle assessment (LCA) methodology and simulates the changes according to different policy and climate change scenarios. The GHGs here includes all the GHGs stipulated in IPCC 5th report. In addition, the carbon sink brought by non-tillage practice is also modelled and reported. The net carbon emissions of different scenarios were calculated by subtracting carbon emissions by carbon sinks. As there are no significant differences in GHG emissions between the different climate scenarios (RCP4.5 and RCP8.5) and the emission curves are identical, only the results for RCP4.5 are shown.

The trends and details of the carbon footprint from the agricultural plantation under different scenarios are shown in Table 6.7. In future years, the GHG emissions will decrease. For the given year, SP is much lower than BAU, while GP is slightly higher than BAU. For instance, for in 2050 the GHG emissions for SP in 9.42 Mt CO_2e, 58.02% of that for BAU. The difference is mainly attributed to the decreasing plantation areas of maize and increasing plantation area of soybean in SP. As the carbon emission intensity of soybean is lower than maize, the SP scenario has lower total GHG emissions. The carbon sink is increasing in future years, and could largely offset the carbon emissions in future years. In 2022, no carbon sink was formed as there were no non-tillage practice. In 2050, the carbon sink could offset around 78% of the carbon emissions for BAU and GP; for SP a net carbon sink (-3.44 Mt CO_2e) could be achieved. For the net carbon emissions, in future years, it will decrease gradually. In the same year, SP is lower that BAU, and there exist limited differences between BAU and GP.

Table 6.7 Carbon footprint of agricultural plantation under different scenarios (CO_2e)

Carbon footprint	Unit	2022	BAU-2025	GP-2025	SP-2025	BAU-2035	GP-2035	SP-2035	BAU-2050	GP-2050	SP-2050
Carbon emissions	Mt	25.77	21.10	21.32	18.46	16.87	17.40	10.18	16.23	17.17	9.42
Carbon sink	Mt	0.00	3.61	3.64	3.63	9.15	9.39	9.18	12.73	13.36	12.86
Net carbon emissions	Mt	25.77	17.49	17.68	14.83	7.72	8.01	0.99	3.49	3.81	-3.44

The economic cost of the total life-cycle GHG emissions from agricultural plantation under different scenarios is shown in Table 6.8 and its patterns in Figure 6.9. The total economic cost was about 736.94 million Yuan in 2022 and will decrease in the future scenarios, which is consistent with the emission trends. In the same year, the economic cost of SP is much smaller than that in BAU and GP. And in 2050, the economic cost is negative, which means that it brings environmental benefits from GHG emissions perspective. In 2035 and 2050, the GHG emissions from soybean plantation are negative, which greatly contributes to the decreasing the overall GHG emissions.

Table 6.8 Economic costs of total life-cycle carbon emissions from agricultural plantation

Carbon footprint	**Unit**	**2022**	**BAU-2025**	**GP-2025**	**SP-2025**	**BAU-2035**	**GP-2035**	**SP-2035**	**BAU-2050**	**GP-2050**	**SP-2050**
Maize	Million yuan	287.13	238.58	241.79	159.56	149.50	154.84	1.30	109.79	116.64	1.03
Rice	Million yuan	388.60	229.44	231.79	209.10	82.64	85.59	60.96	31.43	33.69	23.37
Soybean	Million yuan	61.20	32.09	32.09	55.46	-11.38	-11.38	-33.85	-41.30	-41.30	-122.79
Total	Million yuan	736.94	500.11	505.67	424.11	220.76	229.05	28.40	99.91	109.03	-98.39

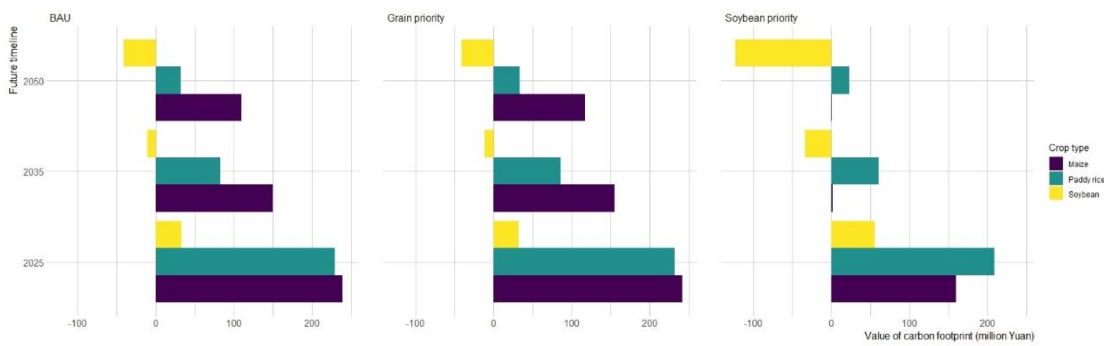

Figure 6.9 Pattern of the economic costs of life-cycle carbon emissions from agricultural plantation

6.2.4 Total economic cost analysis of residual emissions

The economic cost analysis of residuals (air pollutant emissions, water pollutant emissions, and total life-cycle GHG) is shown in Figure 6.10 and the specific cost analysis is shown in Table 6.9. The total economic cost of residuals in 2020 was 1289.84 million Yuan and the economic cost of residuals in future scenarios will decrease, with the main reasons for the increased ratio of non-tillage practices and reduced utilization of fertilizers. For different scenarios, SP is significantly lower than that of BAU and GP, mainly owing to the extensive expansion of soybean plantation and reduction of maize plantation. As soybean has lower fertilizer use and life cycle GHG emissions intensity, both the pollutants and GHG emissions are lower in SP, and the corresponding economic costs are lower. For instance, the residual emissions costs for SP are only 18.66% if that in BAU in 2050. Air emissions, water emissions and GHG emissions are all important sources for residual costs.

The total economic costs between the different climate scenarios (RCP4.5 and RCP8.5) and the emission curves are identical, only the results for RCP4.5 are shown.

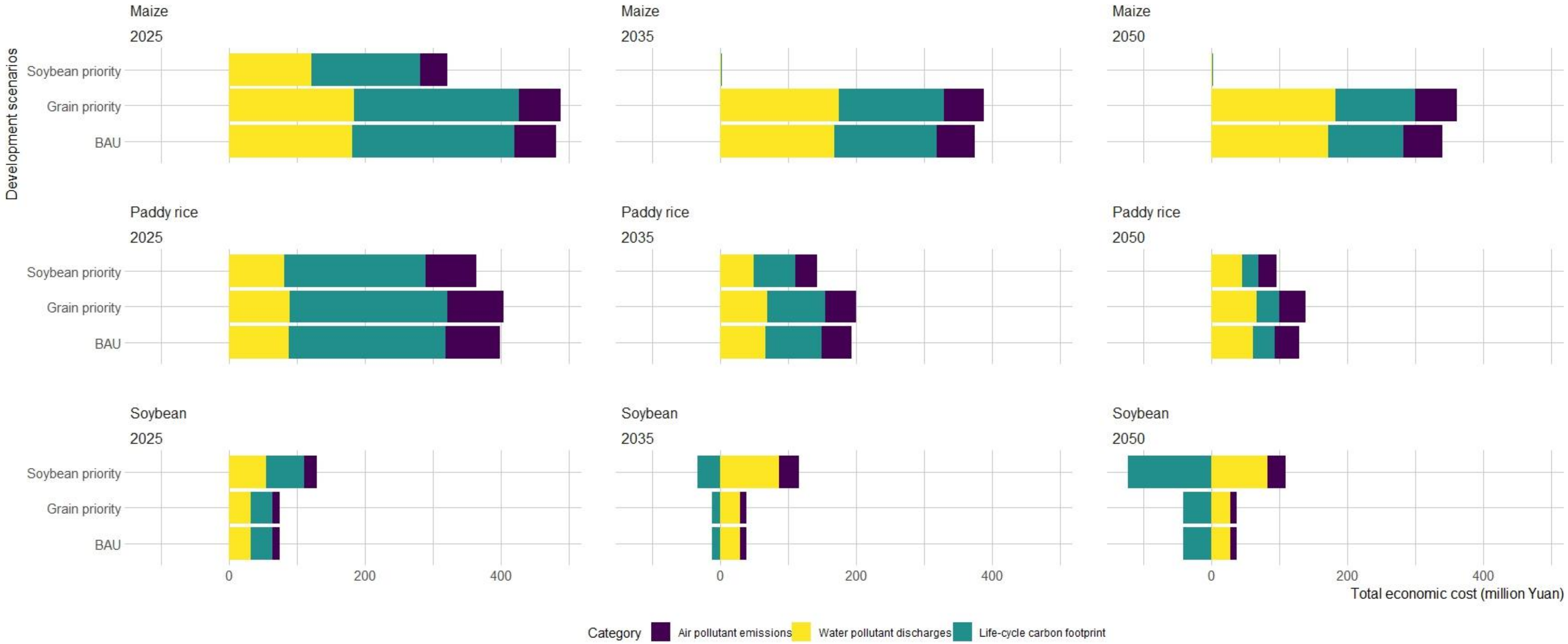

Figure 6.10 Total economic cost of residual emissions from agricultural plantation

Table 6.9 Economic value of agricultural pollution and emission costs in future scenarios (million Yuan)

	Unit	2020	2025-BAU	2025-Pes	2025-Opt	2035-BAU	2035-Pes	2035-Opt	2050-BAU	2050-Pes	2050-Opt
Maize-air emissions	Million Yuan	61.20	60.51	61.33	40.47	56.07	58.07	0.49	57.30	60.88	0.54
Rice-air emissions	Million Yuan	124.55	81.13	81.96	73.93	43.89	45.45	32.37	36.59	39.23	27.21
Soybean-air emissions	Million Yuan	11.56	10.60	10.60	18.32	9.70	9.70	28.83	9.23	9.23	27.43
Sub-air emissions	Million Yuan	197.30	152.24	153.88	132.72	109.65	113.22	61.69	103.12	109.33	55.18
Maize-water emissions	Million Yuan	183.89	181.83	184.28	121.60	168.47	174.50	1.46	172.18	182.93	1.62
Rice-water emissions	Million Yuan	136.98	88.56	89.47	80.71	67.05	69.45	49.46	61.72	66.17	45.90
Soybean-water emissions	Million Yuan	34.72	31.85	31.85	55.03	29.13	29.13	86.63	27.72	27.72	82.41
Sub-water emissions	Million Yuan	355.60	302.23	305.59	257.35	264.65	273.07	137.55	261.62	276.81	129.92
Maize-carbon emissions	Million Yuan	287.13	238.58	241.79	159.56	149.50	154.84	1.30	109.79	116.64	1.03

Rice-carbon emissions	Million Yuan	388.60	229.44	231.79	209.10	82.64	85.59	60.96	31.43	33.69	23.37
Soybean-carbon emissions	Million Yuan	61.20	32.09	32.09	55.46	-11.38	-11.38	-33.85	-41.30	-41.30	-122.79
Sub-carbon emissions	Million Yuan	736.94	500.11	505.67	424.11	220.76	229.05	28.40	99.91	109.03	-98.39
Total	Million Yuan	1289.84	954.58	965.15	814.18	595.06	615.35	227.65	464.66	495.17	86.70

7. Assessment of produced capital

Assessment of produced capital covers the benefits (crops) and costs (farming inputs/outputs) of agricultural production, and the economic cost of soybean expansion from the monetary subsidies provided to the farmers for transitioning from maize and paddy rice to soybean cultivation. The net value (i.e., benefits minus costs) of crop provisioning services is numerically equivalent to the number of provisioning ecosystem services calculated by the residual value method.

7.1 Economic benefits and costs

In examining crop provisioning services over time and across different development pathways, several key trends emerge. Firstly, across all time points (2025, 2035, and 2050), the GP (Grain Priority) pathway consistently leads in total crop provisioning services, with values ranging from 303,557.05 to 445,660.27 million yuan. This represents a substantial increase compared to the other pathways. In contrast, the SP (Soybean Priority) pathway consistently lags behind, with values ranging from 254,989.91 to 276,339.48 million yuan. The BAU pathway falls in between, with values ranging from 300,856.89 to 423,201.66 million yuan. It's evident that the GP pathway performs significantly better than the others in terms of crop provisioning services. In 2050, for instance, the GP pathway provides 445,660.27 million yuan in services, which is 61.2% higher than the SP pathway's 276,339.48 million yuan (Figure 7.1).

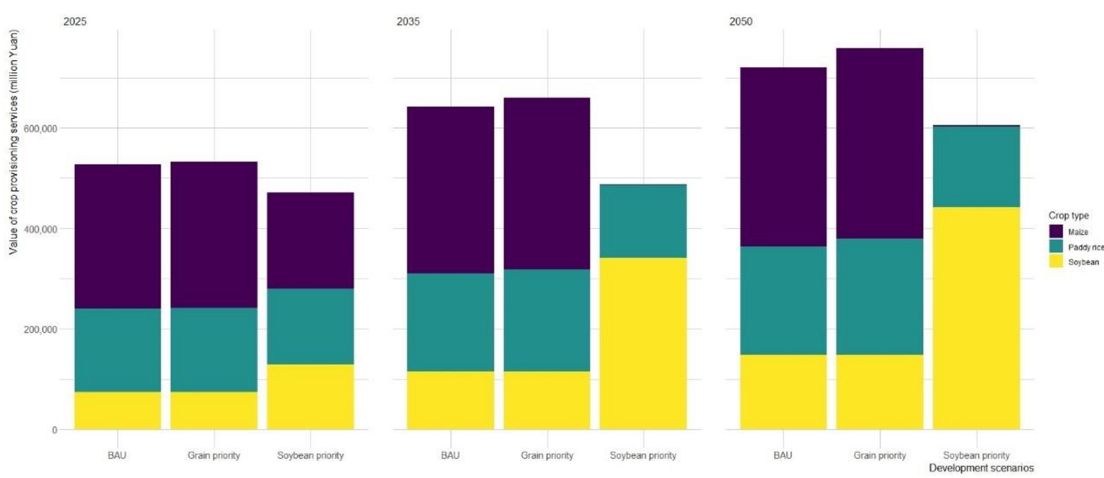

Figure 7.1 Summary of crop provisioning services in Heilongjiang Province

Climate pathways (RCP 4.5 and RCP 8.5) do not contribute to any significant differences to the total provisioning services within the same year, which suggests that climate changes, as represented by these pathways, do not exert a notable influence on crop provisioning services in this context (which is why only the results for RCP 4.5 is shown here). Conversely, the choice of development pathway (BAU, GP, and SP) plays a pivotal role in shaping provisioning services. GP consistently outperforms the others, driven by its emphasis on maize and paddy rice production. In contrast, soybean expansion consistently resulted in lower total provisioning services in the SP pathway (Figure 7.1).

In conclusion, while prioritizing soybean production may enhance soybean safety and yields, our findings suggest that it can have detrimental effects on overall crop provisioning services. This highlights the intricate trade-offs and dynamics between crop types within different development scenarios, emphasizing the need for a balanced and informed approach to land-use planning and policy decisions that take into account the broader implications on ecosystem services.

7.2 Cost of subsidy

The analysis of the cost of subsidy in transitioning from maize and paddy rice to soybean production is a crucial step in understanding the dynamics of the "soybean expansion" policy and its economic sustainability. Maize and paddy rice have traditionally been lucrative crops for farmers, which often makes them hesitant to switch to soybean cultivation. To incentivize this transition and promote soybean expansion, policymakers will have to resort to providing subsidies and support mechanisms. From interviews with local bureaus of agriculture and farmers, we've ascertained that the starting appropriate amount of subsidy is 300 Yuan/mu/annum (4500 Yuan/hectare/annum). By examining the total costs in accordance with land-use change, we can gain valuable insights into the feasibility and impact of policies aimed at promoting soybean cultivation. As the pattern of costs between the different climate scenarios (RCP4.5 and RCP8.5) are identical, only the results for RCP4.5 are shown.

Looking at 2025, both the Business as Usual (BAU) and Grain Priority (GP) scenarios requires approximately 900 million Yuan in subsidies, signifying the initial efforts to encourage soybean expansion within the agricultural landscape. The most significant divergence arises when we analyse the Soybean Priority (SP) scenario in 2025. Here, the subsidies required surge to approximately 10,000 million Yuan (exceeding 1000% compared to the other pathways), in accordance with a 37.6 million mu increase in the total soybean production area (Figure 7.2).

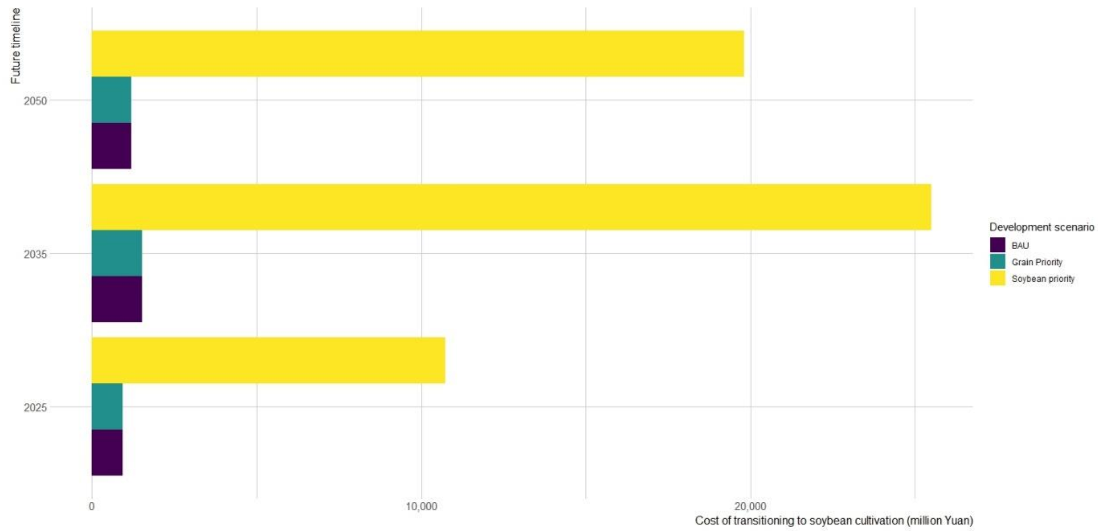

Figure 7.2 Cost of annual subsidy (million Yuan) in transition to soybean cultivation in Heilongjiang Province

Moving forward to 2035 and 2050, the BAU and GP pathways maintain consistent subsidy requirements, hovering around 1,500 and 1,100 million Yuan, respectively. In contrast, the SP scenarios in 2035 and 2050 demand significantly higher subsidy allocations, totalling around 25,000 and 20,000 million Yuan, respectively (the slight decrease from 2035 to 2050 is caused by adjustment of monetary values to 2022 equivalent using the annual CPI of 1.7%). This underscores the SP's ambitious objectives and challenges in promoting soybean cultivation.

The 2050 value appears smaller than the 2035 value because both figures were adjusted to their 2022 equivalents using an annual CPI of 1.7%. This inflation adjustment led to a reduction in the nominal value of subsidies over time. For this analysis, a steady subsidy of **300 Yuan/mu** was applied consistently up to 2050. It's important to note that, in practice, subsidies are subject to change and are expected to increase based on various economic and agricultural factors.

8. Assessment of human capital

The scope of human capital includes the benefits (workforce hired) and costs (human health costs) of agricultural production.

8.1 Quantity and salary of the workforce

The quantity of workforce is proxied by the number of people hired in the agri-food industry shown in Figure 8.1, and the salary payable to the workers shown in Figure 8.2. The patterns for the number of people hired and salary paid between the climate scenarios

(RCP 4.5 and RCP 8.5) are identical, therefore only results for the RCP 4.5 scenario is shown.

Over the years, there have been notable declines in the total hiring and salary in the agricultural sector. In the baseline year 2022, there were approximately 826,969 males and 498,502 females hired, corresponding to approximately 30200 and 14380 million Yuan payable to the workers, respectively. These numbers declined considerably by 2050. In the BAU (Business as Usual) pathway, the hiring decreased to 350,917 males and 250,285 females, corresponding to approximately 17416 and 9272 million Yuan payable to the workers, and representing a decline of approximately 57% for males and around 50% for females, respectively. The GP (Grain Priority) pathway also witnessed a decline, with 376,178 males (totally payable salary of approximately 18511 million Yuan) and 268,302 females hired (totally payable salary of approximately 9871 million Yuan), indicating reductions of around 55% for males and 46% for females. The SP (Soybean Priority) pathway experienced a decrease in male hiring to 260,932 (totally payable salary of approximately 13929 million Yuan) and also a decrease in female hiring to 186,105 (totally payable salary of approximately 7506 million Yuan) compared to the baseline year, representing a decrease of approximately 68% for males and 63% for females. This trend corresponds with steep declines in the male and female hired and their payable salaries in the paddy rice sector, with numbers in the BAU and GP pathways decreasing by around 40-60%, and around 98% in the SP pathway (Figures 8.1 & 8.2).

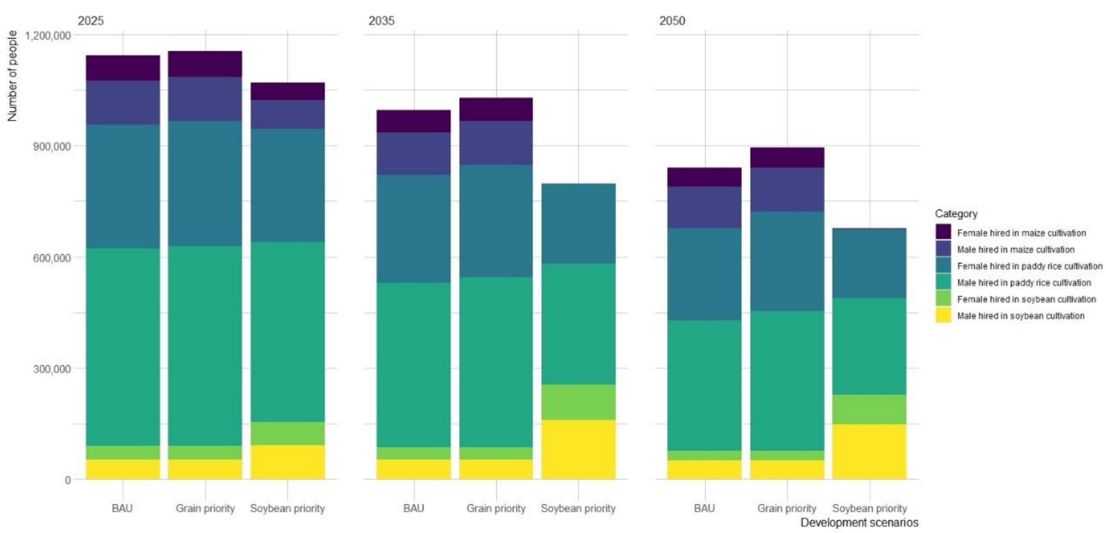

Figure 8.1 Number of people hired in the cultivation of maize, paddy rice, and soybean in Heilongjiang Province

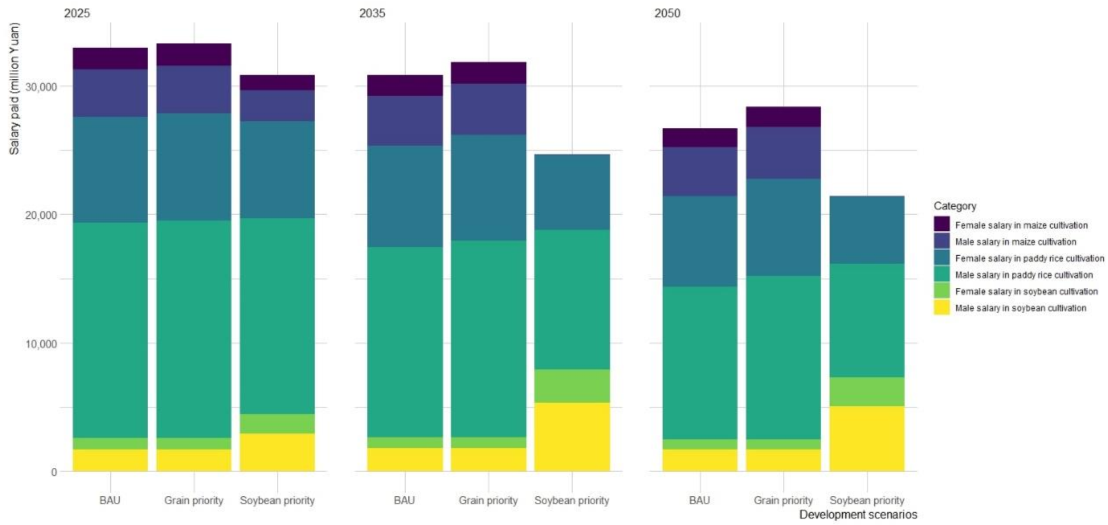

Figure 8.2 Salary payable in the cultivation of maize, paddy rice, and soybean in Heilongjiang Province

Overall, the most significant reductions in hiring and payable salaries occurred in the SP pathway, particularly for paddy rice and maize. These changes are driven by a combination of climate and development factors, including shifts in agricultural priorities.

The SP pathway's prioritization of soybean production over paddy rice and maize, leading to decreased hiring in these crop sectors (Figure 8.1). In comparison, while the soybean cultivation area increased considerably in the SP pathways over the years, it has led to a significant reduction in both male and female hiring in the agricultural sector. This phenomenon can be attributed to the nature of soybean farming, which requires considerably less human labour compared to crops like paddy rice and maize. Also, as we progress towards 2050, a notable shift occurs across all three crops—paddy rice, maize, and soybean—towards large-scale production methods, which are more mechanized, relying on modern farming techniques that are less labour-intensive (see Figure 3.1). Paddy rice, in particular, experiences the most significant decrease of labour required from this transition, contributing to the overall decline in hiring. As a result, the preference for soybean cultivation, coupled with the broader trend of mechanization, has played a pivotal role in diminishing the need for male and female labour in the production sector over time.

However, it is essential to recognize that while soybean expansion may decrease labour requirements in primary production, it can stimulate the development of accompanying industries such as processing and marketing. These downstream activities can add complexity to the production chain and create value-added products, which offer opportunities for product diversification and enhance the profitability of the entire agricultural value chain. In this way, soybean expansion can transform the sector into a more sophisticated and economically lucrative one, ensuring that there might not be a net decrease in employment in terms of the entire agricultural value chain.

8.2 Human capital: health costs

Analysis of the huma health costs include the health of the workforce, and the health impacts of agricultural products on consumers. Health impact illustrated here mainly refers to the direct and indirect loss of life along the supply chain because of agricultural pesticides and fertilizer use. It is first characterized as characterization factor (unit: Disability adjusted life year (DALY)), and then converted into monetary value by using VSL (Value of a Statistical Life). The health impact channels here include occupational health impact because of farmers' exposure to pesticides, atmospheric exposure health impact because of air pollutants emissions from fertilizer and pesticide use, downstream water exposure health impact because of water pollutants emissions from fertilizer and pesticide use, and agricultural product consumption health impact because of the pesticides residuals in the agricultural food consumed.

8.2.1 Occupational exposure health impact

Occupational health exposures mainly involve farmers' exposure to pesticides during spraying through three main channels: digestion, soil inhalation, and dermal contact. Table 6.21 shows the variation of lifetime theoretical maximum contributions (LTMCs) of chemicals under different scenarios.

Table 8.1. The occupation exposure related LTMCs (kg) dynamics in different scenarios

Year	2022	2025	2035	2050
BAU	5.00E-06	4.63E-06	4.21E-06	4.21E-06
GP		5.00E-06	5.00E-06	5.00E-06
SP		4.63E-06	4.21E-06	4.21E-06

The corresponding economic losses for the life adjustment years due to differences in occupational health exposures are shown in Table 6.22. The losses in 2020 are 60.95 million Yuan. Under the pessimistic scenario, the losses are the same as in 2020. In GP scenario, the losses will be the same as in 2022 in future years. In BAU and SP, the losses will be reduced to 56.44 and 51.31 million yuan, respectively, and the losses are the same in future years in each scenario.

Table 8.2 Economic costs of human health related to occupational exposures.

Scenarios	Unit	2022	BAU - 2025	GP-2025	SP-2025	BAU - 2035	GP-2035	SP-2035	BAU - 2050	GP-2050	SP-2050

Occupation exposure	Million yuan	60.95	56.44	60.95	56.44	51.31	60.95	51.31	51.31	60.95	51.31

8.2.2 Atmospheric exposure health impact

The health losses due to exposure to atmospheric pollution emissions caused by agricultural planting are shown in Table 6.23. The health-related economic losses due to exposure to atmospheric pollution emissions in 2022 were 1627.70 million Yuan, and the losses will decrease in future scenarios. In the given year, the GP is higher than BAU, and SP is lower than BAU. For instance, in 2050, the losses in SP are 498.92 million yuan, 52.02% of BAU, and the losses in GP are16.08 million yuan, 105.94% of BAU. The main differences are related to the fertilizer usage reduction in SP scenarios, when soybean is widely promoted.

Table 8.3 Economic costs of human health related to atmospheric exposure in agricultural production.

Scenarios	**Unit**	**2022**	**BAU-2025**	**GP-2025**	**SP-2025**	**BAU-2035**	**GP-2035**	**SP-2035**	**BAU-2050**	**GP-2050**	**SP-2050**
Atmospheric exposure	Million yuan	1627.70	1295.31	1309.44	1120.51	1000.59	1032.89	546.89	959.13	1016.08	498.92

8.2.3 Downstream water exposure health implications

Health losses due to downstream water exposure caused by agricultural plantation are shown in Table 8.4. The economic cost of health losses due to downstream water exposure associated with agriculture in 2020 were 4.19 million Yuan, and the losses will decrease in future scenarios. However, there exist limited differences among different development scenarios in the given year. The decreasing trend in the future years is much related to fertilizer usage reduction.

Table 8.4 Economic costs of human health related to downstream water exposure in agricultural planting

Scenarios	**Unit**	**2022**	**BAU-2025**	**GP-2025**	**SP-2025**	**BAU-2035**	**GP-2035**	**SP-2035**	**BAU-2050**	**GP-2050**	**SP-2050**
Atmospheric exposure	Million yuan	4.19	2.06	2.07	2.11	2.05	2.11	2.05	1.84	1.95	1.80

8.2.4 Health impact of agricultural product consumption exposure

The health impact of agricultural product consumption only account for the effects on human health caused by the intake of pesticide residues in agricultural products through the food chain. Firstly, the lifetime theoretical maximum contributions (LTMCs) of chemicals associated with the consumption of agricultural products were characterised for different scenarios and the detailed results are shown in Table 8.5. Based on this, the health losses due to agricultural products intake under the different scenarios were accounted for, and the results are shown in Table 8.6. The economic loss for the life-adjusted years due to agricultural consumption exposure in 2022 was 4289.39 million Yuan. For GP scenario is the same for the three years as 2022. Under the BAU and SP scenarios, the economic loss in 2025, 2035, and 2050 is reduced to 3965.17, 3604.70, and 3604.70 million Yuan, respectively. The differences mainly come from the difference of pesticides use ratio in different scenarios.

Table 8.5. The food consumption exposure related LTMCs (kg) dynamics in different scenarios

Year	2022	2025	2035	2050
BAU	3.51E-04	3.25E-04	2.96E-04	2.96E-04
GP		3.51E-04	3.51E-04	3.51E-04
SP		3.25E-04	2.96E-04	2.96E-04

Table 8.6 Economic costs of human health related to food consumption exposures.

Scenarios	unit	2022	BAU-2025	GP-2025	SP-2025	BAU-2035	GP-2035	SP-2035	BAU-2050	GP-2050	SP-2050
Occupation exposure	Million yuan	4282.39	3965.17	4282.39	3965.17	3604.70	4282.39	3604.70	3604.70	4282.39	3604.70

8.2.5 Summary of the health exposure effects

The results of the different sources of exposure health impacts are summarised in Table 8.7 and Fig. 8.3, with the most significant sources of exposure health impacts being those from food intake exposure and air exposure. Health losses between scenarios ranged between 4156.74 million and 4975.23 million Yuan, with the SP outperforming the BAU scenario and the BAU scenario outperforming the GP scenario in the given years. In 2050, health losses were 9.97% (460.25 million Yuan) lower in the optimistic scenario and 16.12% (744.39 million Yuan) higher in the pessimistic scenario compared with the BAU scenario.

Table 8.7 The summary of health exposure loss of agricultural plantation

	Unit	2022	BAU-2025	GP-2025	SP-2025	BAU-2035	GP-2035	SP-2035	BAU-2050	GP-2050	SP-2050

Occupation exposure	Million yuan	60.95	56.44	60.95	56.44	51.31	60.95	51.31	51.31	60.95	51.31
Food intake exposure	Million yuan	4282.39	3965.17	4282.39	3965.17	3604.70	4282.39	3604.70	3604.70	4282.39	3604.70
Air exposure	Million yuan	1627.70	1295.31	1309.44	1120.51	1000.59	1032.89	546.89	959.13	1016.08	498.92
Water exposure	Million yuan	4.19	2.06	2.07	2.11	2.05	2.11	2.05	1.84	1.95	1.80
Total	Million yuan	5975.23	5318.98	5654.86	5144.23	4658.65	5378.35	4204.95	4616.98	5361.38	4156.74

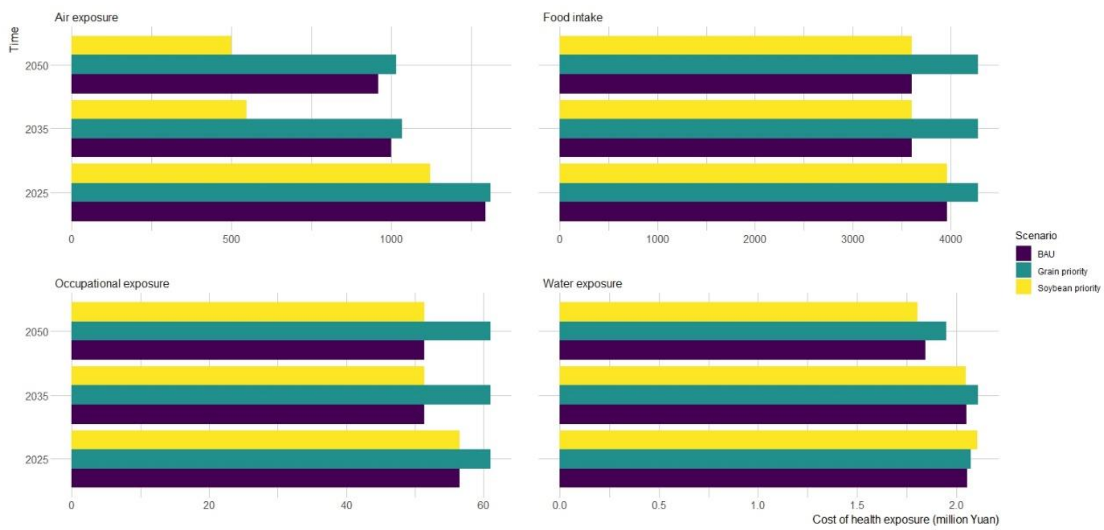

Figure 8.3 Pattern of the total health exposure impacts in agricultural plantation

9. Assessment of social capital

In this report, social capital accounts for women's empowerment and social institution (agricultural cooperatives) in Heilongjiang's agrifood system. A combination of qualitative and quantitative approaches is used to illustrate the state of social capital in both respects.

9.1 Women's empowerment

When comparing the hiring dynamics of males and females based on climate pathways (RCP 4.5 and RCP 8.5) within the same year, we can observe that climate pathways have a limited impact on gender equality in hiring and the patterns are identical. We therefore choose to show only the results for RCP 4.5 in this section.

While the gender dynamics remain relatively stable over time regardless of climate pathways, agricultural development pathways, on the other hand, appear to have a more pronounced effect on the dynamics of male vs. female hiring. When comparing different agricultural development pathways (BAU, GP, and SP) within the same year, some variations in gender dynamics emerge (Figure 8.1). For instance, in 2035 and 2050 under the SP pathways, there are slight increases in female hiring in general, suggesting that the SP pathway may prioritize female employment compared to other pathways. This is because maize production, which highlights male employment, has shifted to more gender-balanced soybean production (Figure 3.1).

The over salary data shows similar trends for male and female. In general, the salary data show a decrease in both male and female salaries over the years. This is evident for all three crops: paddy rice, maize, and soybean. There are notable gender disparities in salaries, with total amount paid to males generally higher than those paid to females across all crop types and pathways. This gender pay gap is consistent over the years (Figure 8.2).

9.2 Social institutions

This study analyses the development of social institutions from the perspectives of how agricultural cooperatives affect the production dynamics of the three main crops. The analysis of agricultural cooperatives is based on data obtained from surveys of cooperatives for maize, paddy rice, and soybean. The smallholder to cooperative ratio in 2022 was 6:4 (cultivated land area) and is projected to change to 5:5 in 2025, 4:6 in 2035, and 3:7 in 2050, signifying the expansion of large-scale production modes.

In terms of the total crop provisioning services generated, approximately 46% of the total services came from large-scale cooperatives in 2022 (baseline year; Figure 9.1) when the smallholder to cooperative area ratio was 6:4. When the smallholder to large-scale cooperatives ratio shifts to 5:5 in 2025, approximately 58% of the total services will come from large-scale cooperatives. This number will grow to approximately 67% in 2035 when the area ratio shifts to 4:6, and to approximately 75% in 2050 when the area ratio shifts to 3:7. This implies a more pronounced transition toward more mechanized, larger-scale agricultural practices, which can lead to increased efficiency and productivity. But this could also have implications for rural employment, as large-scale farming often requires fewer laborers per unit of land. Our results show that as the total number of cooperatives gradually increase from 2025 to 2050, there are massive drops in the total number of households involved in agricultural production, with the largest reduction of the number of households in SP-2050 at approximately 53% (Figure 9.1). This coincides with the patterns revealed in the analysis of human capital (see section 8.1). However, with the continuous advancement of agricultural mechanization, less and less labour is needed in agricultural planting. However, the integration of primary, secondary and tertiary industries will transfer more labour from agricultural cultivation to agricultural processing and sales. In addition, more labour will move to secondary industry and services. Therefore, although soybean expansion will slightly reduce the labour demand in agricultural cultivation, it will not affect the overall employment of labour force.

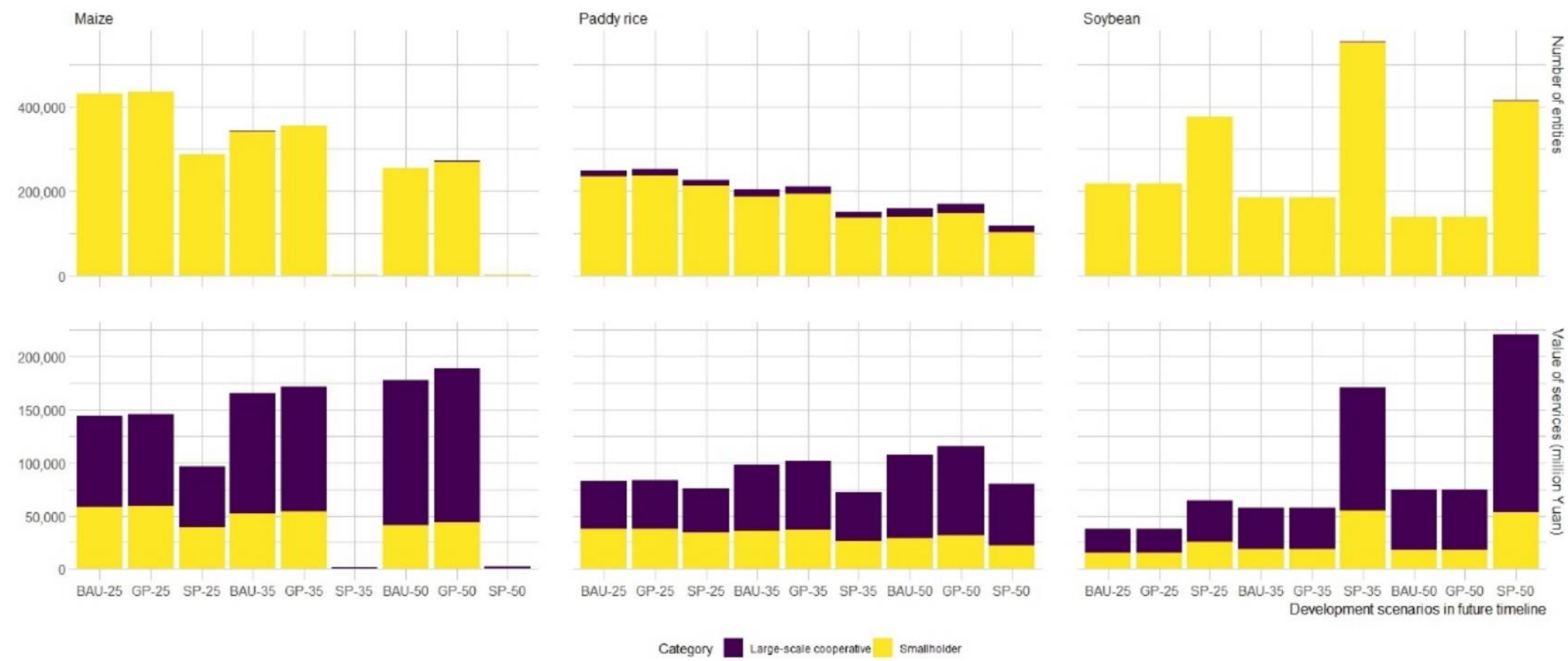

Figure 9.1 Role of agricultural cooperatives in the production of the three main crops in Heilongjiang Province. GP: grain priority, SP: soybean priority.

10.Assessment of the four capitals and sensitivity analysis

10.1 Assessment of the total cost and benefits

The analysis of the total cost and benefit across different scenarios and timelines in Heilongjiang Province provides valuable insights into the trade-offs associated with different soybean expansion scenarios in the future timeline (Figure 10.1).

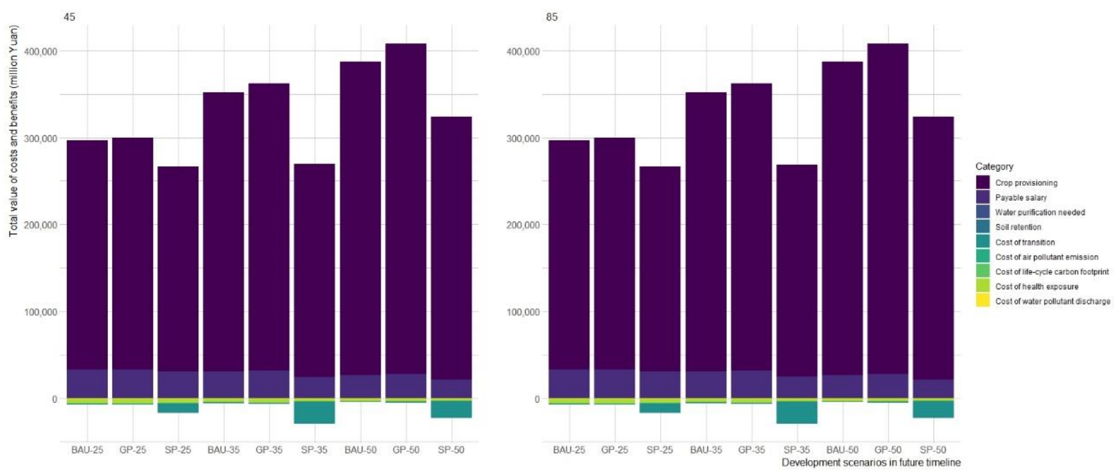

Figure 10.1 Summary of the total benefits and costs of soybean expansion scenarios in Heilongjiang Province

One striking and consistent pattern observed in the results is that the Soybean priority (SP) scenario consistently yields the lowest total value among the three scenarios with Grain priority (GP) at the highest, indicating that SP lags behind in terms of overall economic gain. While the SP scenario does offer certain environmental benefits, such as reduced cost for air emissions, water discharge, carbon emissions, and exposure to negative environmental factors, these advantages do not offset the economic losses incurred. The mostly notable losses come from reduced agricultural income and the subsidies payable to farmers to incentivize their transition to soybean cultivation.

In 2050, the SP scenario incurs lower costs for air, water, GHG emissions, and health exposure, amounting to 33.78, 91.62, 129.38, and 751.40 million Yuan less than the GP scenario, respectively. However, the SP scenario sees decreased crop provisioning services and human salaries by 76,446.51 and 6,943.65 million yuan compared to the GP scenario. Additionally, subsidy alone will cost the SP scenario 18,564.23 million Yuan higher than the GP scenario. Consequently, the SP scenario's net total value is 100,952.02 million Yuan lower than that of the GP scenario.

The advantages of the SP scenario primarily stem from reduced fertilizer and pesticide use, resulting in lower emissions of air and water pollutants, life-cycle carbon emissions, and human health-related exposures. These factors contribute to cost savings of 1,006.18 and 522.83 million yuan compared to the GP and BAU scenarios in 2050. Moreover, the increased food resilience, though challenging to quantify, is noteworthy. The SP scenario's soybean output in 2050 is 30.29 million tons, significantly higher than that of the GP and BAU scenarios at 10.19 million tons, enhancing China's resilience to the fluctuations of international soybean market.

Conversely, the SP scenario's disadvantages include lower grain output and reduced farm employment opportunities caused by decreases in maize and paddy rice cultivations, leading to decreased crop yield and human salaries. These factors result in losses of 83,390.16 and 62,822.12 million Yuan relative to the GP and BAU scenarios in 2050. Additionally, the subsidy cost for expanding soybean cultivation in SP scenario in 2050 totals 19,801.79 million Yuan, surpassing the GP and BAU scenarios by 18,564.23 million Yuan, posing a significant financial burden.

Ultimately, the SP scenario's net total value falls significantly below that of the BAU and GP scenarios. This outcome is primarily due to the inherent costs posed by soybean expansion, such as reduced grain output and the associated subsidy burden. Although the SP scenario brings about unseen benefits, including positive impacts on the environment and human health, these numbers alone cannot compensate for the downsides. Furthermore, the resilience it offers to soybean market fluctuations, while potentially substantial, remains challenging to quantify and monetize accurately at this time. Therefore, despite its potential, the full extent of these benefits cannot be assigned a precise value in monetary terms.

From the domestic point of view, due to Heilongjiang's unique natural conditions, the yield per unit area of soybean is relatively high. Therefore, while enhancing the resilience of the country's food system, the expansion of soybean in Heilongjiang Province may lead to the reduction of rice and corn production, so as to transfer the cultivation of rice and corn to other provinces and regions through the influence of market economy. With the continuous improvement of production technology and the efficient use of land, soybean expansion itself will not pose a great threat to China's food security.

From an international perspective, China's soybean expansion will reduce its soybean imports. However, experts believe this reduction will likely be filled by the increasing food demand caused by the growing population and rising living standards in South Asia and Africa. Therefore, whether the soybean expansion in China will have a significant impact on international trade and what the related environmental implications are still need to be further modelled and assessed.

10.2 Sensitivity analysis

The sensitivity analyses encompass two key perspectives: future climate change and carbon pricing. In examining the effects of climate change, our focus primarily centres on its impact on crop productivity. It's important to note that various climate change pathways, as documented in the literature, yield different consequences for crop productivity. Consequently, our analysis incorporates two distinct climate change pathways, namely RCP 4.5 and RCP 8.5. Specifically, for 2025 and 2035, we utilize near-future climate impact data on crop productivity in Asia, while for 2050, we rely on mid-future impact data for the same region. A comprehensive breakdown of climate change impacts on various crop types can be found in Table 10.1.

Shifting our attention to the matter of carbon pricing, our initial analysis employed a market price of 28.60 Yuan RMB per ton of CO_2-equivalent. In the subsequent sensitivity analysis, we opted to utilize the social cost of carbon (SCC), which is equivalent to 40 USD per ton of carbon, translating to approximately 76.36 Yuan RMB per ton of CO_2-equivalent.

Table 10.1 The impact of climate change on crop productivity

Crop type	**RCP4.5**			**RCP8.5**		
	2025	**2035**	**2050**	**2025**	**2035**	**2050**
Maize	-15.10%	-15.10%	-10.70%	-10.00%	-10.00%	-11.10%
Rice	-2.50%	-2.50%	-1.70%	-2.60%	-2.60%	-4.00%
Soybean	-29.40%	-29.40%	-29.50%	-14.40%	-14.40%	-26.00%

10.2.1 Climate change on net total value

The impact of climate change total net value is detailed in Table 10.2. Climate change has considerable negative impact on the net total value in future scenarios, ranging from 7.55%-22.10%. For most cases, in long term, the impact is more sever. It seems that RCP 4.5 scenarios have larger change ratio than RCP 8.5 scenarios in the given year and given policy pathways. It is mainly because in short (2025& 2035) and medium term (2050), the impact of RCP 4.5 is more prominent than RCP 8.5. It can also be found that SP has larger change ratio that BAU and GP, which is mainly attributed to the large climate change influence rate of soybean than maize and rice. For instance, in 2050, in RCP 4.5 pathway, the influence of climate on BAU, GP and SP is 11.19%, 10.96% and 22.10% respectively.

Table 10.2 The impact of climate change total net value (Million yuan)

Year	RCP pathway	Policy pathway	Total value	Total value considering climate change	Change range	Change ratio
2025	4.5	BAU	289979.04	255245.03	-34734.01	-11.98%
2025	4.5	Grain priority	292281.52	257303.79	-34977.72	-11.97%
2025	4.5	Soybean priority	250201.28	214926.44	-35274.84	-14.10%
2025	8.5	BAU	289979.76	268084.77	-21895.00	-7.55%
2025	8.5	Grain priority	292284.47	270220.10	-22064.37	-7.55%
2025	8.5	Soybean priority	250290.22	229480.07	-20810.15	-8.31%
2035	4.5	BAU	346123.92	301805.19	-44318.73	-12.80%
2035	4.5	Grain priority	355983.69	310683.29	-45300.40	-12.73%
2035	4.5	Soybean priority	240123.23	187941.53	-52181.70	-21.73%
2035	8.5	BAU	346131.92	318766.11	-27365.81	-7.91%
2035	8.5	Grain priority	355966.38	327917.45	-28048.92	-7.88%
2035	8.5	Soybean priority	239899.91	213318.02	-26581.89	-11.08%
2050	4.5	BAU	382555.43	339755.16	-42800.27	-11.19%
2050	4.5	Grain priority	402646.66	358524.98	-44121.68	-10.96%
2050	4.5	Soybean priority	301694.65	235021.84	-66672.80	-22.10%
2050	8.5	BAU	382555.33	339163.63	-43391.69	-11.34%
2050	8.5	Grain priority	402657.24	357721.27	-44935.97	-11.16%
2050	8.5	Soybean priority	301459.90	240625.08	-60834.82	-20.18%

10.2.2 Carbon price

The impact of carbon price on the total net value is minor. As detailed in Table 10.3, the change range varies from 38.10 to 802.80 million yuan. And the change ration varies from 0.02% to 0.27%. As carbon footprint has limited influence in the net total value, the influence of carbon price is also limited.

Table 10.3 The impact of carbon price total net value (Million yuan)

Year	RCP pathway	Policy pathway	Total value	Total value using SCC	Change range	Change ratio
2025	4.5	BAU	289979.04	289185.07	-793.97	-0.27%
2025	4.5	Grain priority	292281.52	291478.72	-802.80	-0.27%
2025	4.5	Soybean priority	250201.28	249527.96	-673.31	-0.27%
2025	8.5	BAU	289979.76	289185.80	-793.97	-0.27%
2025	8.5	Grain priority	292284.47	291481.67	-802.80	-0.27%
2025	8.5	Soybean priority	250290.22	249616.90	-673.31	-0.27%
2035	4.5	BAU	346123.92	345827.82	-296.10	-0.09%
2035	4.5	Grain priority	355983.69	355676.46	-307.23	-0.09%
2035	4.5	Soybean priority	240123.23	240085.13	-38.10	-0.02%
2035	8.5	BAU	346131.92	345835.82	-296.10	-0.09%
2035	8.5	Grain priority	355966.38	355659.15	-307.23	-0.09%
2035	8.5	Soybean priority	239899.91	239861.81	-38.10	-0.02%
2050	4.5	BAU	382555.43	382451.36	-104.07	-0.03%
2050	4.5	Grain priority	402646.66	402533.10	-113.56	-0.03%
2050	4.5	Soybean priority	301694.65	301797.13	102.49	0.03%
2050	8.5	BAU	382555.33	382451.26	-104.07	-0.03%

2050	8.5	Grain priority	402657.24	402543.67	-113.56	-0.03%
2050	8.5	Soybean priority	301459.90	301562.39	102.49	0.03%

11. Policy implications

11.1 Analysing the transition

To facilitate informed decision-making and provide policymakers with empirically grounded insights, this section offers a comprehensive examination of the transition from maize and paddy rice to soybean cultivation per unit of land. By quantifying the costs and benefits associated with this shift, we aim to present a clear and objective assessment of the implications for the soybean expansion practice. This analysis will shed light on the economic, environmental, and societal factors involved in transitioning to soybean cultivation, enabling policymakers to make evidence-based decisions that align with their goals for sustainable and efficient crop provisioning.

The following table (Table 11.1) and figures illustrate the costs and benefits of transitioning per unit of land (ha) from maize (Figure 11.1) and paddy rice (Figure 11.2) to soybean cultivation. The values across development scenarios are largely similar, therefore only the values for the BAU scenarios are shown and analysed. In Table 10.1, the net value (Yuan/ha/annum) is the benefits (improvement in soil conservation, water purification, pollution emissions, and carbon footprint) minus the costs (values lost in crop provisioning changes, labour income changes, and subsidies payable to farmers) associated with converting each hectare of corn/rice into soybean.

Table 11.1 Net value of yearly costs and benefits (Yuan/ha) of transitioning to soybean cultivation from maize and paddy rice. Only BAU scenario is shown.

Time	**Development scenario**	**Source of transition**	**Net value of smallholder land (Yuan/ha)**	**Net value of large-scale land (Yuan/ha)**
2022	na	Maize	-12467.19	-11859.70
2025	BAU	Maize	-15568.46	-16282.45
2035	BAU	Maize	-13971.14	-14415.08
2050	BAU	Maize	-11467.79	-11207.13
2022	na	Paddy rice	-33974.96	-19863.19
2025	BAU	Paddy rice	-23992.58	-10037.04

2035	BAU	Paddy rice	-23867.02	-8738.89
2050	BAU	Paddy rice	-22340.07	-6424.40

There is a clear economic cost to expanding soybean cultivation in the future timeline, including reduced crop services, salaries, and subsidies payable to farmers. These economic costs considerably outweigh the benefits of transitioning to soybean cultivation, which encompass a range of ecosystem services, including soil retention, water purification, air pollutant emissions reduction, water pollutant discharge improvements, carbon footprint reduction, and health benefits.

Notably, the costs in 2022 for transitioning from maize to soybean range from -12467 Yuan (smallholder) to -11859 Yuan (large-scale) per hectare, while transitioning from paddy rice incurs higher costs of -33974 Yuan (smallholder) to -19863 Yuan (large-scale) per hectare. These numbers gradually decrease in the future timelines, but still represent considerable economic losses.

When comparing the source of transitions, i.e., transitioning from maize to soybean and from paddy rice to soybean, some notable differences emerge. On the benefit side, both transitions yield similar positive externalities related to ecosystem services with slightly varying magnitudes. On the cost side, transitioning from paddy rice to soybean tends to result in higher costs compared to transitioning from maize. This is evident in terms of reduced crop services, salaries, and subsidies payable to farmers. This would suggest that pushing for a “paddy to soybean” conversion might require higher incentives compared to other routes.

During our analysis, the input and output characteristics of cultivation, such as fertilizer price, crop price, labour cost, etc., in the future time points have been estimated using historical data to account for market changes over time. The monetary values were then adjusted back to the 2022-equivalents using an annual CPI of 1.7%[15] for comparability. However, a constant subsidy of 300 Yuan/mu (4,500 Yuan/ha) per annum was used to estimate subsidies payable to farmers, which provides valuable insights into the initial economic implications of transitioning to soybean cultivation. It's crucial to acknowledge that this approach likely underestimates the actual subsidies required in the future. Several factors contribute to this underestimation.

[15] http://www.stats.gov.cn/xxgk/jd/sjjd2020/202207/t20220715_1886527.html

Firstly, inflation is an essential consideration. Over time, the purchasing power of currency tends to decrease due to inflationary pressures. As the cost of living, production inputs, and other economic factors rise, the real value of a fixed subsidy amount diminishes. This means that the 300 Yuan per mu subsidy, which may seem adequate now, may not cover the same costs and needs in the future. Secondly, dynamic changes in the agricultural sector, such as shifts in market prices, technological advancements, and alterations in production practices, can impact the financial requirements of farmers. Lastly, unforeseen circumstances and externalities, such as extreme weather events, disease outbreaks, or shifts in global trade dynamics, can exert additional financial pressures on farmers. These unforeseen events may necessitate temporary subsidies or additional financial assistance, which are not accounted for in a static subsidy estimation.

In light of these factors, it becomes evident that our estimations based on a constant subsidy may underestimate the total costs required to incentivize farmers adequately to expand their soybean cultivation in the future. Policymakers should consider the evolving economic landscape and be prepared to adjust subsidy levels accordingly to ensure the success of agricultural policy initiatives.

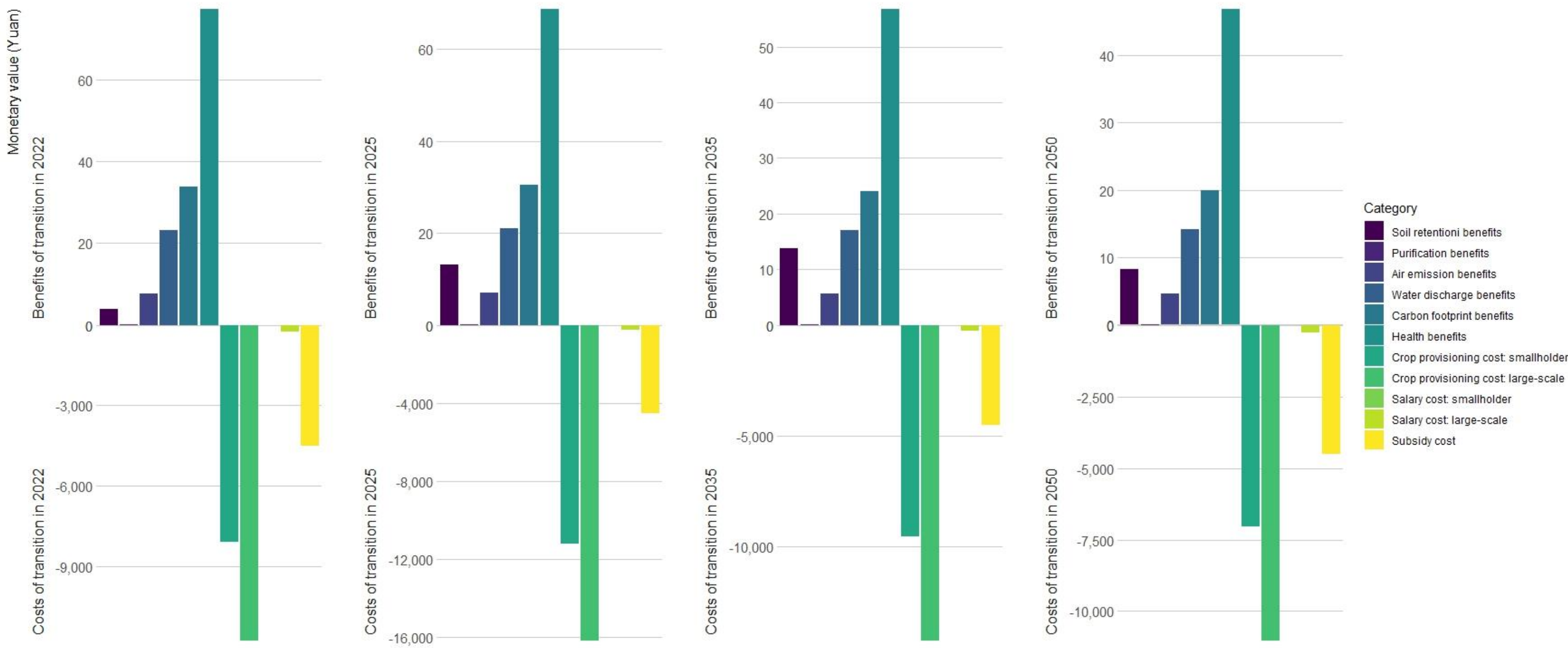

Figure 11.1 Benefits and costs (Yuan) of transitioning from maize to soybean cultivation per ha of land. Smallholder and large-scale numbers denote transitions made in their respective types.

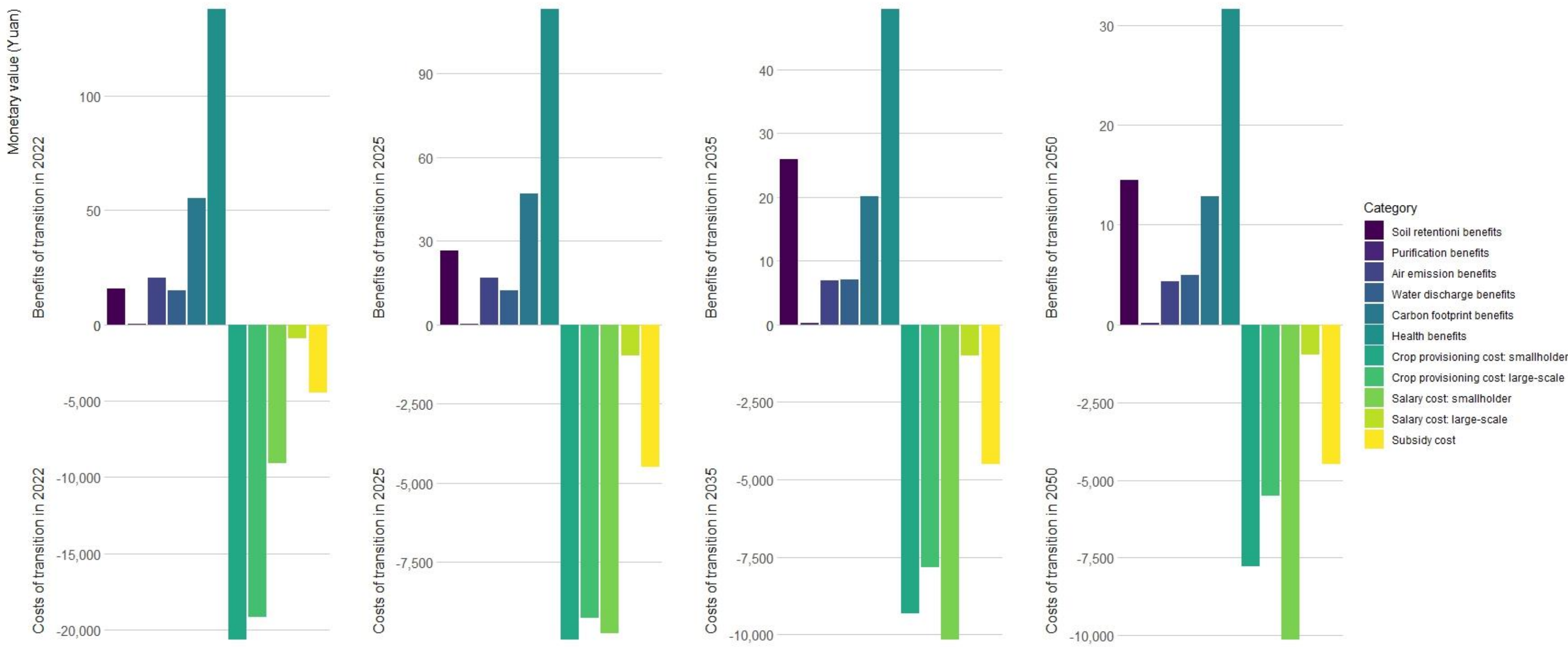

Figure 11.2 Benefits and costs (Yuan) of transitioning from paddy rice to soybean cultivation per ha of land. Smallholder and large-scale numbers denote transitions made in their respective types.

11.2 Conclusion

The analysis provides a comprehensive framework for policymakers to make well-informed decisions regarding the transition from maize and paddy rice to soybean cultivation. The result underscores the intricate trade-offs inherent in soybean expansion policies, addressing the environmental, socioeconomic, and food security objectives sought in Heilongjiang Province. Yet, our analysis has revealed that finding the desired equilibrium is a multifaceted challenge. While promoting environmentally friendly practices is essential, these practices should not compromise the well-being of local livelihoods. Policymakers must meticulously weigh various factors to balance short-term economic gains and long-term sustainability.

The transition from smallholder to large-scale production reflects a broader trend of modernization taking place nationally. Large-scale farming offers notable efficiency benefits but also brings challenges, including land consolidation and potential labour displacement. When crafting crop transition policies, policymakers must be attuned to the possible social and economic consequences, such as livelihood shifts and rural-urban migration. Continuous monitoring of these trends and supporting smallholders and large-scale operations is crucial.

Environmental and Socioeconomic Aspects

Our analysis underscores the multifaceted challenges presented by soybean expansion policies, especially when considering the economic costs and environmental benefits. It highlights the significant gap between the existing cost and benefit values and the potential role of oilseed crop security in bridging this gap. While promoting soybean cultivation can enhance the local environment and agroecosystem sustainability, its impact on the socioeconomic system is profound. Policies must be crafted to holistically integrate economic, environmental, and social factors, with particular attention to their effects on local livelihoods. Policymakers should enhance support, both in terms of policy and technical assistance, for the farming sector to mitigate the repercussions of transitioning to soybean cultivation.

It is essential to recognize that while soybean expansion may decrease labour requirements in primary production, it can stimulate the development of accompanying industries such as processing and marketing, potentially balancing employment changes. These downstream activities can also add complexity to the production chain and create value-added products, which offer opportunities for product diversification and enhance the profitability of the entire agricultural value chain. In this way, soybean expansion can transform the sector into a more sophisticated and economically lucrative one, ensuring that there might not be a net decrease in employment in the entire agricultural value chain.

Food System Resilience

Our Soybean Priority (SP) scenario projects a potential soybean output of up to 30,000,000 tons in Heilongjiang by 2050. This substantial increase in domestic production could substantially reduce China's dependence on soybean imports, lowering the import dependency rate from 82% to 63% under the proper conditions. However, quantifying the resilience of domestic oilseed crop markets remains challenging. Such resilience is typically influenced by intricate factors like national-level reserve programs, policy incentives, and international trade agreements, making it difficult to assign a direct monetary value. Nevertheless, our project provides valuable data to support agri-food system transformation from natural, social, and human aspects, fostering a more balanced approach to meet socioeconomic needs, environmental protection, and food security.

Global Market Influences

While we hold uncertainties about the precise impact of China's soybean expansion on other soybean production countries, it is likely that emerging markets in Africa, South Asia, and Southeast Asia will gradually absorb the soybean output resulting from China's expansion, allowing for a more balanced distribution of resources and production. However, more solid and comprehensive modelling and analysis are needed to draw conclusive insights in this regard. It is essential to conduct further research to understand the complex dynamics of global soybean markets and the implications of China's soybean expansion.

11.3 Policy mainstreaming

Chinese Academy of Sciences (CAS) is a ministry-level institution under the State Council which is the chief administrative authority of China. Among the multiple roles CAS plays in science and technology, it serves as an advisory body to the State Council. Customized policy recommendations on national soybean expansion policy will be drafted by the Institute of Geographic Sciences and Natural Resources Research (IGSNRR) and submitted to the General Office of the State Council through CAS.

National policy priorities that are relevant to the study include "Opinions of the Central Committee of the Communist Party of China and the State Council on Doing Key Tasks Well in Promoting Rural Revitalization in 2023"[16] (the “No. 1 document” issued by the Central Committee that proposed expanding soybean and oilseed cultivation to increase production capacity) and "Implementation Opinions on Implementing the Key Tasks of Comprehensive Rural Revitalization in 2023 by the CPC Central Committee and the State Council"[17], in which the Ministry of Agriculture and Rural Affairs indicates to increase

[16] http://www.lswz.gov.cn/html/xinwen/2023-02/13/content_273655.shtml

[17] http://www.gov.cn/zhengce/zhengceku/2023-02/22/content_5742671.htm

soybean planting areas by promoting crop rotation of grain and beans in Northeast China and expanding the planting of soybeans on saline-alkali land and abandoned land.

In addition, the year 2024 to 2025 is the key period for the formulation of the 15^{th} Five-Year Plan across the country. Several rounds of consultations will be held before the Plan is finally endorsed. Recommendations from the study will be feed into the consultation process to support the drafting of the relevant 15^{th} Five-Year Plans.

By the end of 2023, the study has received comments from various ends including officials at national and subnational levels and academic experts. The main aspect of the feedback are as follows.

China is a major agricultural producer, supporting 20% of the world's population with 6% of the world's water resources and 9% of its arable land. At the same time, China is one of the richest countries in terms of biodiversity and was one of the first countries to propose the "carbon peaking and carbon neutrality" strategy.

Heilongjiang is China’s most crucial area for commercial grain production, yielding 11-12% of the nation’s grain and 47-48% of its soybeans, making the restructuring of its planting systems vitally important for national food security and the ecological restoration of its black soil.

The findings from the TEEBAgriFood Heilongjiang study have significant implications for advancing ecologically and climate-smart agriculture and for the rational optimization of planting structures. It will provide insights on balancing environmental costs, resource efficiency, food security and rural development.

The study also raised awareness among different stakeholders regarding the notion that stable biodiversity systems and healthy ecosystems are important for safeguarding the yield and quality of agri-food systems.

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