Data and Methodology Report (1st draft)

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

Implementation in China

【Deliverable 2.1】

February, 2022

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Introduction

"The Economics of Ecosystems and Biodiversity: Promoting a Sustainable Agriculture and Food Sector" project Steering Committee in China, chaired by Chinese Research Academy of Environmental Sciences, Ministry of Ecology and Environment of China, agreed in July 2020 for the TEEBAgriFood China initiative to focus on ecological and green development of Tengchong's agriculture system, with an aim to understand the dependencies and impacts of Tengchong's diverse agriculture system on natural, produced, human and social capitals along its value chain, and with such information to inform better decision-making.

Later on in October 2020, the first consultation meeting at the local level provided a chance for the project implementation team to understand the overall situation of Tengchong, in particular, its agriculture system and future development priorities, land use patterns, and other social-economic drivers. Based on this, the Scoping and Scenario Setting report was drafted and then reviewed at the second project Steering Committee meeting in February 2021.

This report is the second in a series of reports produced through the project. The first, 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 (detail in section 1). This report presents an outline of the processes and methodologies that will be used by the research team to measure and value the dependencies and impacts of Tengchong's diverse agriculture systems on the four capitals including ecosystem services and biodiversity. The research, with its multidisciplinary and multidimensional nature, requires that the research team be comprised of experts from different fields and consult different stakeholders during the process.

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.

1. Scenario-setting

Tengchong has a diverse and multi-functional agricultural system, one that the scenario analysis attempts to fully depict by detailing possible policy changes taking place in the main agricultural aspects under the business-as-usual (BAU), optimistic and pessimistic pathways throughout the three key time points for national development plans. The study also integrates climate change and other socio-economic (GDP, demographics, and urbanization) drivers in the modeling. In total, 3 policy pathways (BAU, optimistic and pessimistic), 2 climate change scenarios (RCP4.5 and RCP 8.5), and 3 time points (the year 2025, 2035, and 2050) have been taken into consideration, resulting in 18 scenarios.

In the BAU scenarios, policy changes that are known already and very likely to occur are built in, representing the baseline, while the optimistic/pessimistic scenarios take into account claimed positive/negative policy changes. Through such design, the study hopes to inform the optimization of current policies.

1.1 Temporal series

The study proposes to set the short-term time point for scenario analysis at 2025, the completion year of China's 14th Five-year Plan, which is also the first five years to achieve quality and efficiency in agriculture for a moderately prosperous society. The mid-term time point for scenario analysis will be 2035, which is the target year for the basic realization of modernization in China and an important point for the basic realization of modern green production and sustainable consumption. The year 2050, the target year for China's second century goal, will be set as the long-term time point.

1.2 Policy drivers

Tengchong's main agricultural aspects include beef cattle breeding, plantation, and industrial integration. The beef cattle breeding encompasses four main models – ecological pasture, standardized breeding, combined planting-breeding, and conventional free-range, while the plantation comprises three – conventional crops, endemic species, and under-canopy plantation. Their characteristics are explained as follows.

Beef cattle breeding:

- **Ecological pasture**: building eco-pastures in concentrated and continuous grasslands for beef cattle breeding, and developing tourism to enhance the economic, cultural, and ecological benefits.
- **Standardized breeding**: enterprises that concentrate on raising beef cattle at a scale of 300 heads/farm. Feed is mainly sourced from pasture grass, purchased commercial feed and agricultural and forestry residues, etc. According to the plan, one beef cattle needs to be equipped with 2 mu of forage crops, which is made from processed cornstalk and forage cultivated during idle seasons on farmlands. The beef cattle manure is treated by anaerobic fermentation to produce organic fertilizer for return to the fields for growing herbs, fruits, vegetables, etc., to replace traditional chemical fertilizers and pesticides.
- **Combined planting-breeding**: small farmers combining farming and livestock breeding. Small farmers feed their beef cattle with agricultural and forestry residues, planting fodder and finely chopped grass pasture, and the manure produced by the cattle is simply composted and returned to the fields to achieve the recycling of nutrients such as nitrogen and phosphorus.
- **Conventional free-range**: smallholder farmers raise beef cattle by grazing or penned breeding, with feed mainly coming from pasture or agricultural and forestry residues, and animal manure is discharged into the surrounding environment without treatment.

Plantation:

- **Conventional crops**: mainly refers to the cultivation of major food crops (rice, maize, and wheat), but also includes oilseed rape, non-forest herbs, vegetables, fruit, and tea cultivation.
- **Endemic species**: the cultivation of endemic germplasm resources with genetic and cultural value. Locally favorite is xi-hong-ruan rice[1].

[1] Xi-hong-ruan rice, known for its fine soft grain, red skin, and good quality, is a relatively scarce local rice variety in Tengchong. It was named as one of the "Yunnan top ten rice varieties".

- **Under-canopy plantation**: primarily medicinal herbs.

The study captures policy changes in the abovementioned dimensions. Details of the policy scenario-setting are elaborated on below.

1.2.1 Baseline policy scenarios

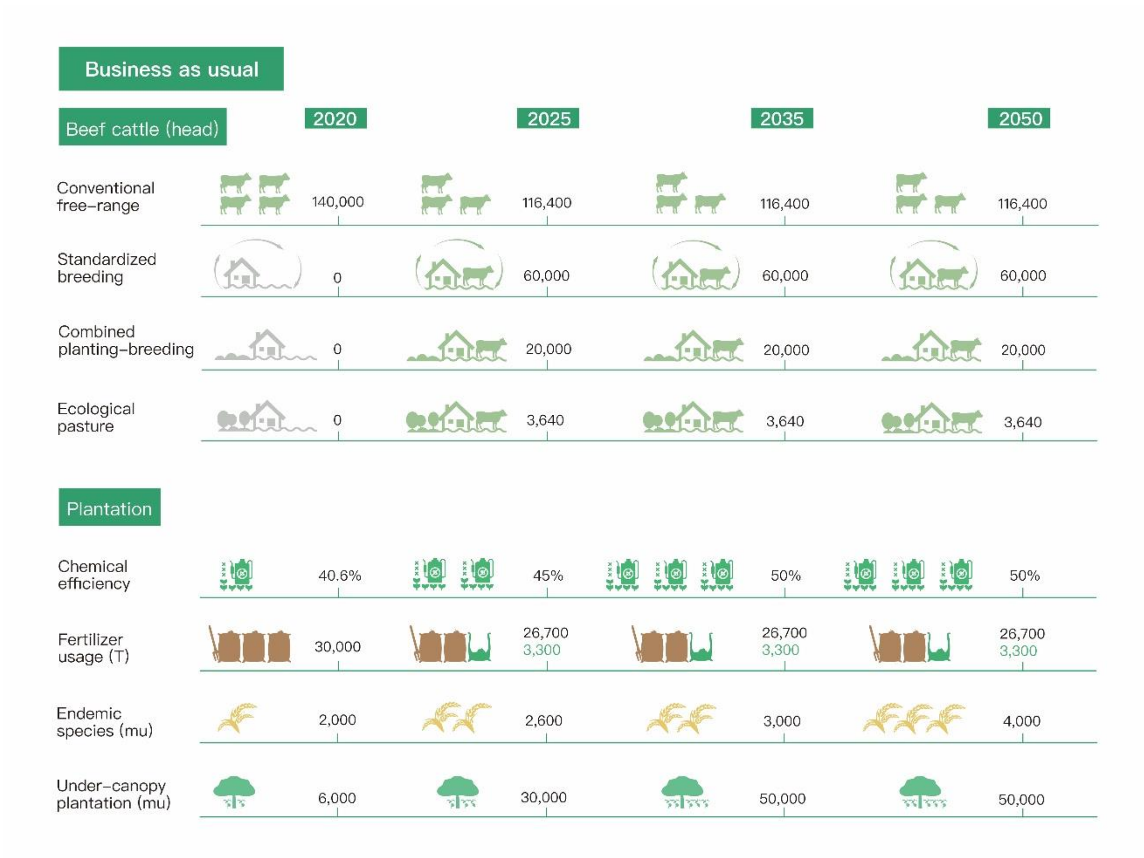

Figure 1. The business as usual (BAU) scenario-setting

- Beef cattle breeding

Total beef cattle breeding grows from 140,000 heads in 2020 to 200,000 heads in 2025 and remains unchanged in 2035 and 2050.

Ecological pasture: by 2025, 20,000 mu (appr. 1333 ha) of new ecological pastures and 3,640 beef cattle will be added, development of ecological tourism and integrated development of primary, secondary, and tertiary sectors of the economy is to remain unchanged in 2035 and 2050.

Standardized breeding: By 2025, 200 new standardized farms, 60,000 new beef cattle, and 120,000 mu (8000ha) of new supporting forage land will be present, which will remain unchanged in 2035 and 2050.

Combined planting-breeding: By 2025, 10,000 small farmers will be guided to shift from the conventional free-range mode to the combined planting-breeding mode, with a conversion scale of 20,000 beef cattle heads; the same will be maintained in 2035 and 2050.

Conventional free-range: by 2025, the number of free-range beef cattle will be reduced by 23,600 heads; the number will remain unchanged in 2035 and 2050.

- Plantation

Conventional crops:

i) the efficiency of pesticide use in the plantation sector is gradually increasing from 40.6% to 45% by 2025, and then to 50% by 2035 and 2050;

ii) the use of chemical fertilizers will be reduced from 30,000 tonnes at present to 26,700 tonnes in 2025, and the use of farmyard manure and organic fertilizers will be increased by 3,300 tonnes, which will remain unchanged in 2035 and 2050;

iii) the area planted remains unchanged and the feed required for large-scale beef cattle breeding is made from processed cornstalk and forage cultivated during idle seasons on farmlands, with no impact on the area and production of grain.

Endemic species: by 2025, the xi-hong-ruan rice planting area will increase by 30% from 2020 to 2,600 mu (appr. 173 ha), by 2035 an increase of 50% to 3,000 mu (200 ha), and by 2050 an increase of 100% to 4,000 mu (appr. 267 ha).

Under-canopy plantation: area under plantation will increase from 6,000 mu (2019; 400 ha) to 30,000 mu (2025; 2000 ha), to 50,000 mu (2035; appr. 3,000 ha), and to remain unchanged by 2050.

- Industrial integration

Foster agricultural product processing enterprises, accelerate product quality and brand certification, develop rural tourism and agricultural tourism based on modern agriculture, enhance the integration of agriculture and culture, and promote the integration of ~~one, two and three~~the primary, secondary, and tertiary industries.

1.2.2 Optimistic policy scenarios

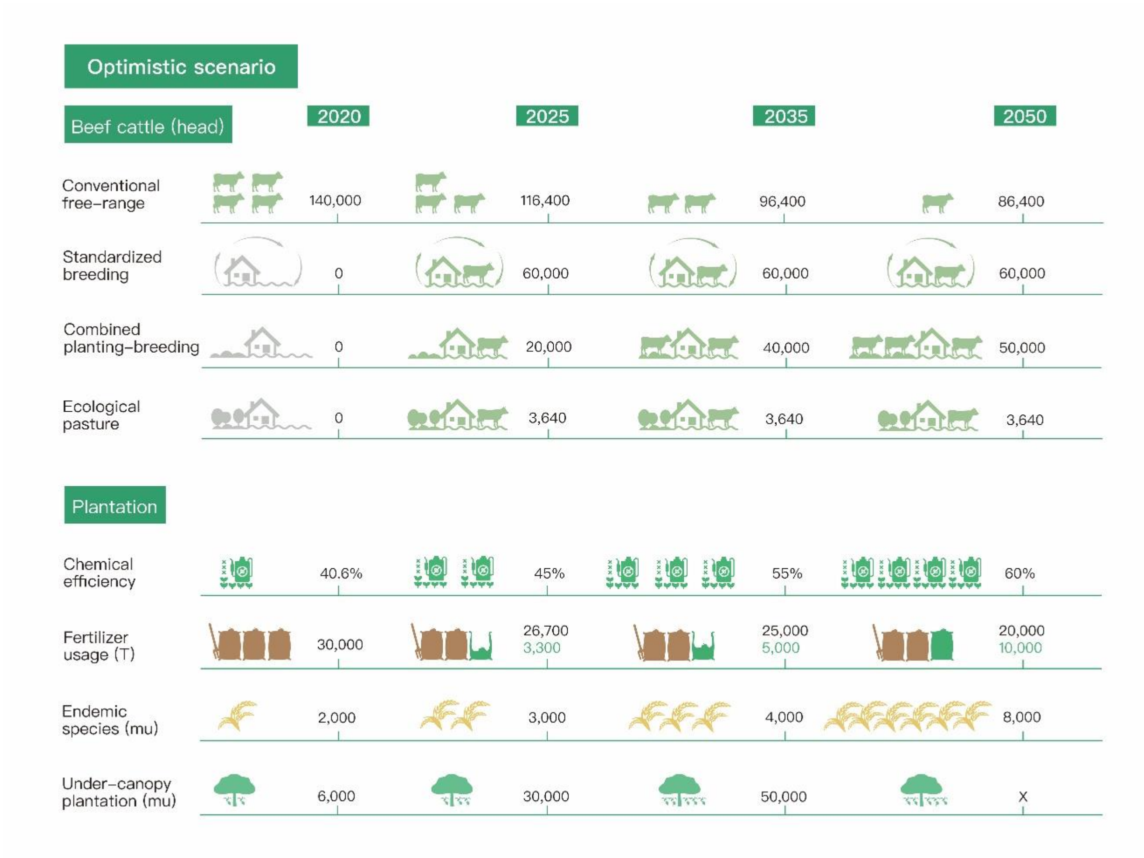

Figure 2. The optimistic scenario-setting

- Beef cattle breeding

Total beef cattle breeding increases from 140,000 head in 2020 to 200,000 heads in 2025 and remains constant in 2035 and 2050.

Ecological pasture: by 2025, 20,000 mu (appr. 1333 ha) of new ecological pastures and 3,640 beef cattle will be added, development of ecological tourism and integrated development of primary, secondary, and tertiary sectors of the economy is to remain unchanged in 2035 and 2050.

Standardized breeding: By 2025, 200 new standardized farms, 60,000 new beef cattle, and 120,000 mu (8000ha) of new supporting forage land will be present, which will remain unchanged in 2035 and 2050.

Combined planting-breeding: By 2025, 10,000 small farmers will be guided to shift from the conventional free-range mode to the combined planting-breeding mode, with a conversion scale of 20,000 beef cattle head; in 2035, 10,000 more small farmers will be guided on the basis of 2025, with a new conversion scale of 20,000 head; in 2050, another 5,000 small farmers will be further guided based on 2035, with a new conversion scale of 10,000 head.

Conventional free-range: by 2025, the number of free-range beef cattle will be reduced by 23,600, and by 2035 by a further 20,000, and by 2050 an additional reduction of 10,000.

- Plantation

Conventional crops:

i) the efficiency of pesticide use will increase from 40.6% in 2020 to 45% by 2025, 55% by 2035, and 60% by 2050;

ii) the use of chemical fertilizers will be reduced from the current 30,000 tonnes to 26,700 tonnes in 2025, and the use of farmyard manure and organic fertilizers will increase by 3,300 tonnes; the use of chemical fertilizers will be reduced to 25,000 tonnes in 2035, and the use of farmyard manure and organic fertilizers will increase by 5,000 tonnes; the use of chemical fertilizers will be reduced to 20,000 tonnes in 2050, and the use of farmyard manure and organic fertilizers will increase by 10,000 tonnes;

iii) the area under cultivation remains unchanged.

Endemic species: by 2025, the xi-hong-ruan rice planting area will increase by 50% from 2020 to 3,000 mu (200 ha), by 2035 an increase of 100% to 4,000 mu (appr. 267 ha), and by 2050 an increase of 300% to 8,000 mu (appr. 534 ha).

Under-canopy plantation: area under plantation will increase from 6,000 mu (2019; 400 ha) to 30,000 mu (2025; 2000 ha), to 50,000 mu (2035; appr. 3,000 ha), and to cover all available under-canopy areas (specific range to be determined by later research and GIS analysis).

- Industrial integration

Foster agricultural product processing enterprises, accelerate product quality and brand certification, develop rural tourism and agricultural tourism based on modern agriculture, enhance the integration of agriculture and culture, and promote the integration of the primary, secondary, and tertiary industries.

1.1.3 Pessimistic policy scenarios

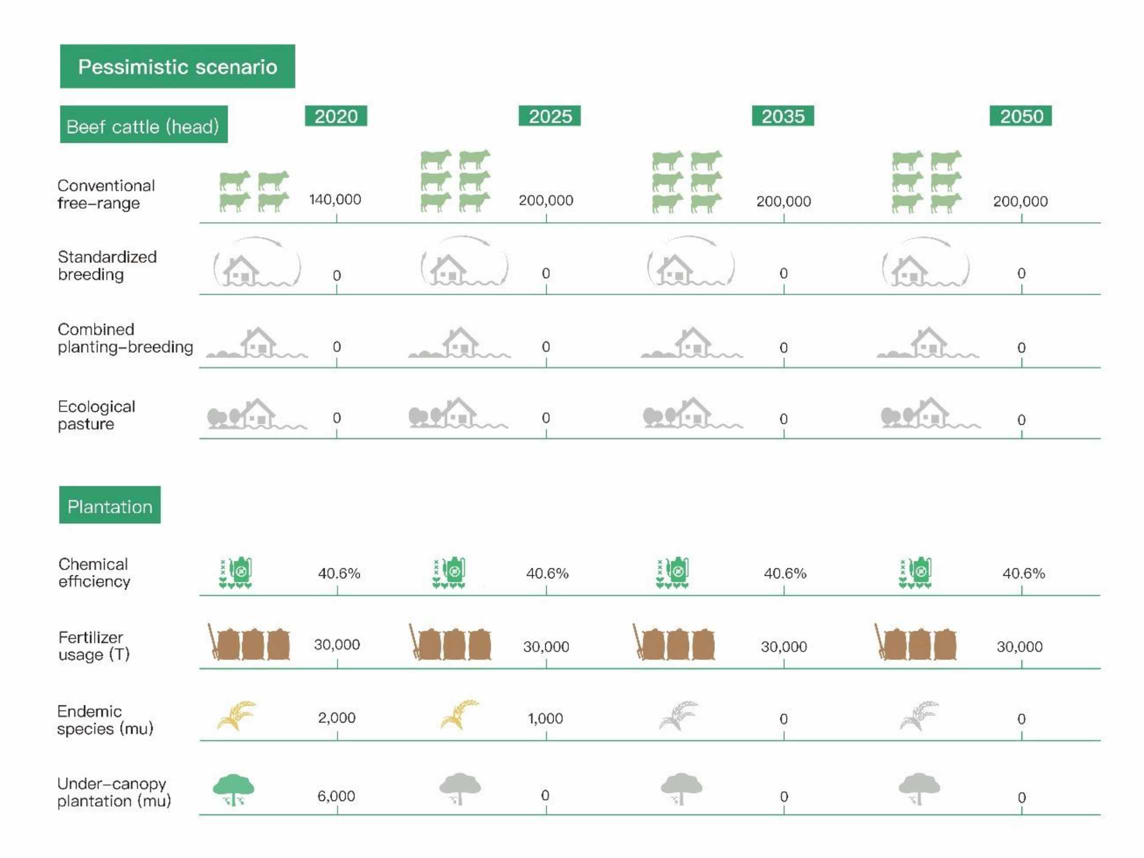

Figure 3. The pessimistic scenario-setting

- Beef cattle breeding

Total beef cattle breeding grows from 140,000 head in 2020 to 200,000 head in 2025 and remains unchanged in 2035 and 2050.

Ecological pasture: no development of ecological pastures.

Standardized breeding: no development of large-scale breeding.

Combined planting-breeding: no development of combined planting-breeding.

Conventional free-range: By 2025, 200,000 beef cattle head will all be raised in conventional free-range mode, with no centralised treatment of livestock manure. In 2035 and 2050 these numbers will remain unchanged.

- Plantation

Conventional crops:

i) the efficiency of pesticide use will remain at the current level of 40.6% (2020) in 2025, 2035, and 2050;

ii) the use of chemical fertilizers will remain at 30,000 tonnes in 2025, 2035, and 2050, and the use of organic fertilizers and farmyard manure will be reduced to zero;

iii) the area under cultivation will remain unchanged.

Endemic species: By 2025, the planted area of xi-hong-ruan rice will be reduced by 50% compared to 2020 (1,000 mu, appr. 66.67 ha), and by 2035 the planted area will be reduced to 0, which is to remain unchanged by 2050.

Under-canopy plantation: by 2025, the under-canopy plantation area will be reduced to 0, and by 2035 and 2050 it will remain unchanged.

- Industrial integration

This scenario assumes no new agricultural product processing enterprises, no product quality and brand certification, and a low level of integrated development of primary, secondary and tertiary industries.

1.3 Climate and other socio-economic drivers

The scenarios also take into account drivers that policymakers do not directly influence, such as GDP, demographics, and urbanization. Then the three scenario sets (BAU, optimistic and pessimistic) were set up and crossed with two climate change scenarios (medium greenhouse gas emission scenario RCP4.5 and high greenhouse gas emission scenario RCP8.5) to obtain six future scenario sets, with each including the 3 time-points (Table 1).

Table 1 Scenario sets developed in the study

Scenario set 1	Scenario set 2	Scenario set 3
RCP4.5 + BAU scenario (2025, 2035, 2050)	RCP4.5 + optimistic scenario (2025, 2035, 2050)	RCP4.5 + pessimistic scenario (2025, 2035, 2050)
Scenario set 4	**Scenario set 5**	**Scenario set 6**
RCP8.5 + BAU scenario (2025, 2035, 2050)	RCP8.5 + optimistic scenario (2025, 2035, 2050)	RCP8.5 + pessimistic scenario (2025, 2035, 2050)

~~These scenarios were developed to reflect future development caused by both natural (climate change) and socio-economic (policy, demographic and urbanization) drivers.~~

~~The plantation scenarios encompass three main modes of cultivation, including conventional crops, endemic species, and under-canopy plantation. The breeding scenarios encompass four main modes of the beef cattle industry, including ecological pasture, standardized breeding, combined planting-breeding, and conventional free-range.~~

2. Data collection

The project team, since its 1st local stakeholder consultation meeting in Oct. 2020, has been communicating with and collecting materials from the local authorities, through on-site visits and online exchanges, covering basic information and official planning documents of relevant agricultural industries. Representative materials collected include:

1) Map of livestock and poultry breeding restricted and prohibited areas
2) Distribution of beef cattle farms under the "1+3+6" development model[2]

[2] The "1+3+6" development model for beef cattle farms plans to achieve an increase of more than 60,000 head in

3) Report on arable land quality in Tengchong City (2019)
4) Tengchong's medicinal herbs planning map
5) Meteorological data 2000-2020 (monthly)
6) Maincrop production methods and material inputs
7) Map of certain nature reserves and protected areas
8) Macro-level forest survey results
9) Locations of pasture and grassland

In addition to materials obtained from local authorities, the project implementation team also accessed online open sources to acquire accessible spatial data and census data, which include land cover type, basic geographic information data, socio-economic data, and climate projection data. Among them, rainfall and temperature data under RCP4.5 and RCP8.5 scenarios are from the climate projection of China based on the RegCM4.6 (2007-2099). Data required including its sources are listed in Table 2.

Table 2 Multi-source data for land-use land-cover change modelling

Data type	Indicator	Year	Data resolution	Data source
Land use data	land use	2000-2020	30m	Resource and Environment Science and Data Center (http://www.resdc.cn/)
Socio-economic driver	Administrative boundaries			
	GDP	2015	1000m	Resource and Environment Science and Data Center (http://www.resdc.cn/)
	Population	2015	100m	WorldPop (www.worldpop.org/)
	Distance from administrative center	2015	30m	National Catalogue Service for Geographic Information (www.webmap.cn)
	Distance from major roads	2015	30m	National Catalogue Service for Geographic Information (www.webmap.cn)
	Distance to highway and railroad	2015	30m	National Catalogue Service for Geographic Information (www.webmap.cn)
Natural driver	Digital elevation model (DEM)	2015	30m	Resource and Environment Science and Data Center (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 from water system	2015	30m	National Catalogue Service for Geographic Information (www.webmap.cn)
	Temperature	2015	1000m	Resource and Environment Science and Data Center (http://www.resdc.cn/)
	Rainfall	2015	1000m	Resource and Environment Science and Data Center (http://www.resdc.cn/)

stock by 2022, which means that in principle, each of the city's administrative villages should build at least one standardized cattle farm (the 1), fitted to carry no less than 300 head (the 3). An accompanying forage and feed base of 600 mu (40 ha; 2 mu per head) will be established around each farm (the 6).

Future climate scenario	Temperature	2020-2035	0.25°	National Tibetan Plateau Data Center (data.tpdc.ac.cn)
	Rainfall	2020-2035	0.25°	National Tibetan Plateau Data Center (data.tpdc.ac.cn)

Data on the inputs and outputs of the agricultural sectors in Tengchong City, including plantation, cattle breeding, and herbal medicine, were also collected through face-to-face interviews with representative businesses, agricultural associations, and farmer households in May 2021 during the 2nd local stakeholder consultation. In total, 8 companies, 1 agricultural cooperative, and 12 farmer households were interviewed. The interviews revolved around four aspects – i) basic information, ii) construction, operation, and maintenance, iii) products and sales, iv) social and human capitals, detailed as follows.

1) Beef cattle breeding
    a. Infrastructure (built-up/pasture size, topography, material input, financial investment, maintenance input/cost)
    b. Personnel (number of workforces, gender, age, education, skill/training, social security, income)
    c. Finances (source of financial investment, level of industrial integration, annual revenue)
    d. Operations (type and origin of cattle, breeding cycle, quantity in stock/slaughtered in 2020, material/labour/machinery input, waste processing, processing/marketing/sales, institutional support)
    e. Eco-tourism (investment, type of attraction, revenue)
2) Herbal medicine
    a. Personnel (number of workforces, gender, age, education, skill/training, social security, income)
    b. Infrastructure (material input, maintenance input/cost)
    c. Finances (financial investment, annual revenue)
    d. Operations (type of herb, origin and usage of seed/seedling, material/labor/machinery input, tillage information, processing/marketing/sales, institutional support)
3) Plantation (including the cultivation of traditional and endemic crops, fruit and vegetable, and medicinal herbs, and household-scale breeding of cattle, swine and poultry)
    a. Personnel (number of workforces, gender, age, education, skill/training, social security, income)
    b. Infrastructure (material input, maintenance input/cost)
    c. Finances (financial investment, annual revenue)
    d. Operations (type of herb, origin and usage of seed/seedling, material/labor/machinery input, tillage information, processing/marketing/sales, institutional support)

3. Land-use land-cover (LULC) change modeling

The scenario analysis will encompass the spatially-explicit modeling, which will be built upon a predictive land-use/land-cover (LULC) change modeling that integrates existing biophysical data and future predictions to offer landscape assessment and spatial land-use forecast. Multi-source data is needed to provide a more complete picture of the contribution of the various elements to land-use change. Data required for the scenario analysis is listed in Table 2.

3.1 Land use simulation

The simulation of land use patterns is based on a geographic cellular automata (CA) background. Land use and its changes are driven by both natural and human factors, and different factors act in different ways and with different intensities on land-use changes. The land use grid of the study area will be transformed into individual raster grids of 30m*30m units, and the main class of each grid is selected for the assignment. This process divides the study area into a number of cells that function as the most basic unit of the CA process. In the simulation process, these cells each correspond to a certain land-use type. The historical trend of land-use change, land suitability, and related policy and economic factors constitute the rules, which together determine the possibility of land use type conversion in each cell.

Natural conditions are the basis of land cover and land use distribution and play a dominant role, while human factors such as social, economic, technological, and policy factors have a decisive influence on spatial and temporal changes in land use. The simulation of land-use change by using cellular automata not only takes into account the influence of natural factors such as soil conditions, climate conditions, and geomorphological conditions, but also the influence of human factors such as policy, and at the same time consider the historical trend of land-use change, and carry out a dynamic simulation to obtain the future land use situation.

The purpose of geographic CA is to assist in land-use policymaking. However, most existing CA models have focused too much on the enhancement of simulation techniques and the correction of transformation rules, and relatively little has considered how simulation techniques can be used to deepen the understanding of the underlying drivers of land use. Therefore, existing CA models come up short in exploring the causes of land-use change and simulating patch-level changes in multiple land-use types in a spatial and temporal dynamic manner, especially for natural land types such as woodlands and grasslands.

Among the existing models, the Transformation Analysis Strategy (TAS) is too complex and has low flexibility, with too much emphasis on the mining algorithm. Pattern analysis strategy (PAS) is not based on land-use change over time and lacks the temporal concept, therefore does not carry the capacity to excavate the driving mechanisms of land-use change. In this study, the FLUS model is used to simulate land use, consider different future greenhouse gas emission targets, and characterize climate change with rainfall and temperature changes.

The FLUS model was established by integrating Artificial Neural Networks (ANN) algorithm and Roulette wheel selection mechanism based on System Dynamics (SD) model and metacellular automata (CA) model, which can be used to simulate land-use change scenarios under the effect of various natural, social and economic drivers. The main body of the model is divided into two parts, the ANN-based Probability of Occurrence Estimation (ANN) module, and the Self-Adaptive Inertia and Competition mechanism (SICA) module. The ANN module is a biological neural network-inspired machine learning model, which is a nonlinear dynamical system and can achieve a better approximation of nonlinear functions with self-learning, self-organizing, and self-adaptive features, and can effectively integrate different data types to achieve parallel processing of multivariate and complex information. Therefore, it can synergistically integrate multiple types of driving data (natural, social, and economic) and simulate the probability of suitability distribution of each land type under a predefined scenario to establish the correlation between different land types and driving factors. At the same time, the FLUS model innovatively introduces an adaptive inertia competition mechanism based on roulette selection based on the traditional CA model to deal with the uncertainty and relative complexity of changes in multiple land types under the synergistic effects of nature, society, and economy, to achieve a more accurate simulation of land-use change.

3.2 Climate scenarios

Different future GHG emission targets are considered to characterize climate change in terms of rainfall and temperature changes. The future climate data are based on projections made under RCP4.5 and RCP8.5 using the RegCM4.6 model emission scenarios. Downscaling is performed to fit the scale of the study before specific use. The RCP4.5 emission scenario is a radiative forcing value of 4.5 W m^{-2} corresponding to GHG in 2100 while RCP8.5 refers to a radiative forcing value of 8.5 W m^{-2} corresponding to GHG concentrations in 2100. The RCP4.5 emission scenario is an optimistic emission scenario representing an intermediate mitigation scenario - GHG emissions peak at mid-century and then begin to decline. The RCP8.5 emissions scenario is a pessimistic emissions scenario representing a "business-as-usual" approach-a future climate scenario caused by continued increases in GHG emissions during this century. The RCP4.5 GHG emissions trends are consistent with China's national conditions. The RCP8.5 GHG emission trends are consistent with rapid global economic development; therefore, this study projected the precipitation and temperature in the study area in 2025, 2035, and 2050 under these two climate scenarios, respectively. The raw resolution of the above climate projection data is 0.25° × 0.25° for the data. This coarse resolution prediction data was first downscaled using the bilinear interpolation method, which is a simple method to improve the horizontal resolution, and it retains the original field characteristics of the input at a higher level. Then, the regional statistics of the data under the two emission scenarios after downscaling are determined to obtain the spatial raster data of precipitation and temperature in the respective years. This, combined with different land-use conversion rules and land use weights that are set according to different development scenarios, is used to simulate the spatial distribution of different land use/cover types. The land-use structure of the study area in 2025, 2035, and 2050 under different climate-development scenarios are thus obtained.

3.3 Development scenarios

The three development scenarios are business as usual (BAU), optimistic, and pessimistic. The land use capacity is projected based on CA-Markov, and the land use structure data of

2015-2020 and 2005-2020 are used to obtain the land use data of Tengchong City in the three-time points. The year 2005-2020 is used to simulate the long-term changes, while 2015-2020 is used to simulate the short-term changes.

Table 3 Restriction matrix under BAU scenario

	Built land	Farmland	Grassland	Forest	Garden	Bare land	Waterbody
Built land	1	1	1	0	0	0	1
Farmland	1	1	1	1	0	1	1
Grassland	1	1	1	1	1	1	1
Forest	0	1	0	1	1	0	0
Garden	1	1	1	1	1	1	1
Bare land	1	1	1	1	1	1	0
Waterbody	1	0	1	0	1	1	1

4. Ecosystem service assessment

The ecosystem services we will be analyzing are crop and livestock provisioning, recreation enabling, waterflow regulation, water purification, soil erosion control, pollination, and carbon storage and sequestration.

4.1 Crop provisioning service

As part of the biomass provisioning services, crop provisioning service is a final ecosystem service that measures the ecosystem contributions to the growth of cultivated plants that are harvested by economic units for various uses such as the production of food, fiber, fodder, and energy.

Here, the land rental price method will be used to measure the ecosystem contributions to the growth of grains (rice, wheat, and maize), oilseed rape, medicinal herb, vegetable, tea, and fruit.

In the case of annual and perennial crops, ecosystem contribution is provided by the land, which is combined with other inputs, such as labor, capital, seeds, etc., to produce the final product, the crop. The contribution of each input can be estimated by a production function, where the output (Y) is a function of inputs (labor, L), (capital, K), (land, W), and (other factors, Z). The production function is expressed as:

$$Y = F(L, K, W, Z) \qquad (1)$$

If all factors, including land, were priced in a competitive market, their prices would be equal to their marginal value products. In the case of land, taking its rental price per hectare as P_W, this condition is written in mathematical terms as:

$$P_Y \frac{\partial Y}{\partial W} = P_W \qquad (2)$$

The same applies to all other inputs. In addition, if production takes place in an economy that satisfies certain competitive equilibrium conditions, then the production function also satisfies the following conditions:

$$Y = \frac{\partial Y}{\partial L}L + \frac{\partial Y}{\partial K}K + \frac{\partial Y}{\partial W}W + \frac{\partial Y}{\partial Z}Z \qquad (3)$$

in which case, combining (2) and (3) gives:

$$P_Y Y = P_L L + P_K K + P_w W + P_z Z \qquad (4)$$

In this case, the contribution of the land as an Ecosystem Service is the equivalent of the payment received for the production of the crop. The beneficiary is the economic owner of the land. If only part of the land is leased, the remaining part can be estimated based on the leased land (offering adjustment for quality differences, e.g., soil fertility). The key advantage of this method is that rental data often differ across regions (e.g., more fertile land can command higher rental prices) so that valuation results are spatially heterogeneous. However, in the case of Tengchong, spatial heterogeneity of the rental price may not be sufficient enough. In which case the contribution of land may also be calculated, using the resource rent method, by deducing its residual from the value of the crops when payments to all other factors, including paid and unpaid labor, capital equipment that is rented or owned (in which case depreciation), and material costs, have been subtracted.

4.2 Livestock provisioning service

Livestock provisioning services are the ecosystem contributions of economic units for the growth of cultivated livestock and livestock products (e.g., meat, milk, eggs, wool, hides) for various uses (mainly food production). It is a final ecosystem service.

To measure beef cattle provisioning service in Tengchong, the primary approach will be to use the rental value method, supplemented by the residual value method when spatial heterogeneity of the pastureland does not meet analysis demands.

4.3 Recreation enabling service

Recreation-related services refer to the ecosystem contributions, particularly through their biophysical characteristics and qualities, to enable people to use and enjoy the environment through direct, on-site, physical, and experiential interaction with it. This includes services for local and non-local people (i.e., visitors, including tourists). This is a final ecosystem service.

In Tengchong's agri-food system, ecosystems provide a range of recreational and cultural services in eco-pastures, tea, and under-canopy plantation gardens. These places are usually run by farm operators who rent the land. Some places may charge admission fees and visitors may also spend money on particular recreational activities on-site. In all cases, the starting point is to assess whether an entrance fee has been paid. This charge usually includes some maintenance costs but is not a price based on a balance of demand and supply for the service. A balanced price should be between the cost of providing the service and the value to the service user. It is important to assess whether the entrance fee makes economic sense. If so, after deducting costs, these fees can be used to value the ES provided. The importance of entrance fees can be assessed by comparing their revenues to the cost of maintaining the place.

In the case where entrance fees cannot be established, the consumer expenditure approach (CE) will be applied. Only the costs that are made to access the site (e.g., fuel, transport costs, tolls, and fees, excluding broader cost categories such as food) will be included.

4.4 Water flow regulation

The provision of fresh water is one of the ecosystem services that provide multiple social benefits to humans. The water production capacity of ecosystems is dependent on the dynamic hydrological cycle within the system and is influenced by climate, soils, vegetation, topography, and land-use structure to show variability.

Water is an irreplaceable natural resource for industrial and agricultural production, economic development, and environmental improvement. In recent years, the uncertainty of water supply due to climate change has seriously threatened the security and stability of the ecosystem, affecting changes in the natural landscape and the layout of regional population and socio-economic development. The unreasonable overuse of scarce water resources has exacerbated desertification, with some rivers breaking, wetlands disappearing and groundwater levels dropping year by year.

The InVEST Water Yield model estimates the relative contributions of water from different parts of a landscape, offering insight into how changes in land-use patterns affect annual surface water yield and hydropower production. The model runs on a gridded map. It estimates the quantity and value of water used for hydropower production from each sub-watershed in the study area. It has three components, which run sequentially. First, it determines the amount of water running off each pixel as the precipitation minus the fraction of the water that undergoes evapotranspiration. The model does not differentiate between surface, subsurface, and baseflow, but assumes that all water yield from a pixel reaches the point of interest via one of these pathways. This model then sums and averages water yield to the sub-watershed level. The pixel-scale calculations allow us to represent the heterogeneity of key driving factors in water yield such as soil type, precipitation, vegetation type, etc. Based on the physical amount of water yield, we estimate the economic value by multiple the local water price. The equations show as below:

$$S_i^{WY} = P_i - QF_i - AET_i$$

$$E_i^{WY} = V_i * S^{WY}$$

For each pixel i, where S_i^{WY} refers to the supply of WY, P_i is precipitation, QF_i is the quick flow estimated through the Soil conservation service – curved number (SCS-CN) approach, AET_i is the actual evapotranspiration, V_i is the local water price.

Table 3 Data requirement of the InVEST water provisioning model

Data	Type	Description
Land use/land cover	Raster	Map of land use/land cover codes
Average annual precipitation (mm)	Raster	Map of average annual precipitation
Average annual reference evapotranspiration (mm)	Raster	Map of evapotranspiration values
Water prices (monetary)	/	
Digital Elevation Model	Raster	Map of elevation above sea level

Area of Interest	Vector/ polygon	A map of areas over which to aggregate and summarize the final results
Biophysical Table	CSV	A table mapping each LULC code to biophysical properties of the corresponding LULC class

4.5 Water purification

Water purification in ecosystems refers to the process and ability of ecosystems to retain water over a given time and space scale. Water quality purification is a fundamental service provided by ecosystems. The material-energy cycle of ecosystems has processing and purifying effect on the quality of the water environment. And when the level of impact goes beyond the ecosystem's ability to clean itself, the decline in water quality will have a direct impact on human well-being and health.

Land-use change, particularly the shift to agricultural land, has dramatically altered natural nutrient cycles. The overuse of pesticides and fertilizers and the discharge of irrigation and industrial effluents directly lead to a decline in water quality and the enrichment of nutrients such as nitrogen, phosphorus, and potassium in water, causing ecological problems such as water pollution, damage to aquatic life, and salinisation of land.

One way to reduce non-point source pollution is to reduce the number of anthropogenic inputs (i.e. fertilizer management). When this option fails, ecosystems can provide a purification service by retaining or degrading pollutants before they enter the stream. For instance, vegetation can remove pollutants by storing them in tissue or releasing them back to the environment in another form. Soils can also store and trap some soluble pollutants. Wetlands can slow flow long enough for pollutants to be taken up by vegetation. Riparian vegetation is particularly important in this regard, often serving as the last barrier before pollutants enter a stream.

Land-use planners from government agencies to environmental groups need information regarding the contribution of ecosystems to mitigating water pollution. Specifically, they require spatial information on nutrient export and areas with the highest filtration. The nutrient delivery and retention model provides this information for non-point source pollutants. The model was designed for nutrients (nitrogen and phosphorous) given that data are available on the loading rates and filtration rates of the pollutant of interest.

The model uses a simple mass balance approach, describing the movement of a mass of nutrients through space. Unlike more sophisticated nutrient models, the model does not represent the details of the nutrient cycle but rather represents the long-term, steady-state flow of nutrients through empirical relationships. Sources of nutrients across the landscape also called nutrient loads, are determined based on a land use/land cover (LULC) map and associated loading rates. Nutrient loads can then be divided into sediment-bound and dissolved parts, which will be transported through surface and subsurface flow, respectively, stopping when they reach a stream. In a second step, delivery factors are computed for each pixel based on the properties of pixels belonging to the same flow path (in particular their slope and retention efficiency of the land use). At the watershed/sub-watershed outlet, the nutrient export is computed as the sum of the pixel-level contributions. The equations are shown as below:

$$ALV_i = HSS_i \cdot pol_i$$

ALV_i is the adjusted load value of pixel i. pol_i is the output coefficient of pixel i, and HSS_i is the hydrological sensitivity score of the calculation method of pixel i:

$$\mathrm{HSS_i} = \frac{\lambda_\mathrm{i}}{\overline{\lambda_\mathrm{w}}}$$

λ_i is the runoff coefficient at pixel i , while $\overline{\lambda_\mathrm{w}}$ is the average runoff coefficient index.

$$\lambda_x = \log\left(\sum_u \gamma_u\right)$$

$\sum_u \gamma_u$ represents a spatially varying pixel of runoff potential, which is the ability to deliver nutrients downstream. This raster can be defined as the is the total water yield into pixel x, which can be calculated using the quick flow index from the InVEST Seasonal Water Yield model.

$$E_i^{WP} = (v_N + v_p) * S_i^{WP}$$

where v_N and v_p are the treatment costs of nitrogen and phosphorus. S_i^{WP} is the amount of water retained (as was calculated in the water flow regulation model in section 4.4).

Table 4 Data requirement of the InVEST water purification model

Data	Type	Description
Land use/land cover	Raster	Map of land use/land cover codes
Nutrient Runoff Proxy	Raster	Map of runoff potential, the capacity to transport nutrients downstream
Watersheds	Vector/ polygon	Map of the boundaries of the watershed(s) over which to aggregate the model results
Wastewater treatment cost of nitrogen and phosphorus	/	
Digital Elevation Model	Raster	Map of elevation above sea level
Area of Interest	Vector/ polygon	A map of areas over which to aggregate and summarize the final results
Biophysical Table	CSV	A table mapping each LULC code to biophysical properties of the corresponding LULC class

4.6 Soil erosion control

Erosion and overland sediment retention are natural processes that govern the sediment concentration in streams. Sediment dynamics at the catchment scale are mainly determined by climate (in particular rain intensity), soil properties, topography, and vegetation; and anthropogenic factors such as agricultural activities or dam construction and operation. Main sediment sources include overland erosion (soil particles detached and transported by rain and overland flow), gullies (channels that concentrate flow), bank erosion, and mass erosion (or landslides). Sinks include on-slope, floodplain or instream deposition, and reservoir retention. Conversion of land use and changes in land management practices may dramatically modify the amount of sediment running off a catchment. The magnitude of this effect is primarily governed by: i) the main sediment sources (land-use change will have a smaller effect in catchments where sediments are not primarily coming from overland flow); and ii) the spatial distribution of sediment sources and sinks (for example, land-use change will have a smaller effect if the sediment sources are buffered by vegetation).

Increases in sediment yield are observed in many places in the world, dramatically affecting water quality and reservoir management. The sediment retention service provided by natural landscapes is of great interest to water managers. Understanding where the sediments are produced and delivered allows managers to design improved strategies for reducing sediment loads. Changes in sediment load can have impacts on downstream irrigation, water treatment, recreation, and reservoir performance. Outputs from the sediment model include the sediment load delivered to the stream at an annual time scale, as well as the amount of sediment eroded in the catchment and retained by vegetation and topographic features.

The sediment delivery module is a spatially-explicit model working at the spatial resolution of the input digital elevation model (DEM) raster. For each pixel, the model first computes the amount of annual soil loss from that pixel, then computes the sediment delivery ratio (SDR), which is the proportion of soil loss actually reaching the stream. Once sediment reaches the stream, we assume that it ends up at the catchment outlet, thus no in-stream processes are modeled.

Ecological factors in the ecosystem (e.g. vegetation cover) enhance the prevention of soil erosion and prevent soil runoff into rivers, helping to maintain the soil's ability to filter pollutants and regulate water quality. Calculated by the classical modified universal soil loss equation.

$$S_i^{SC} = R_i * K_i * L_i * S_{i^*}(1 - C_i * P_i)$$

R is rainfall erosivity, K is soil erodibility, L is a slope length-gradient factor (unitless), C is a cover-management factor (unitless), and Pi is a support practice factor.

$$E_i^{SC} = S^{SC} * (m_N * v_N + m_P * v_P + m_K * v_K)$$

The economic value of soil retention services can be calculated by multiplying the local fertilizers.

Table 5 Data requirement of the InVEST soil conservation model

Data	Type	Description
Land use/land cover	Raster	Map of land use/land cover codes
Nutrient Runoff Proxy	Raster	Map of runoff potential, the capacity to transport nutrients downstream
Erosivity	Raster	Map of rainfall erosivity, reflecting the intensity and duration of rainfall in the area of interest
Watersheds	Vector/ polygon	Map of the boundaries of the watershed(s) over which to aggregate the model results

Soil Erodibility	Raster	Map of soil erodibility, the susceptibility of soil particles to detachment and transport by rainfall and runoff
Digital Elevation Model	Raster	Map of elevation above sea level
Area of Interest	Vector/ polygon	A map of areas over which to aggregate and summarize the final results
Biophysical Table	CSV	A table mapping each LULC code to biophysical properties of the corresponding LULC class
The price of local fertilizers	/	

4.7 Pollination

Seventy-five percent of globally important crops are partially or completely dependent on animal pollination. Crop pollination by bees and other animals is a potentially valuable ecosystem service in many landscapes of mixed agricultural and natural habitats. Pollination can increase the yield, quality, and stability of fruit and seed crops as diverse as tomato, canola, watermelon, coffee, sunflower, almond, and cacao. Despite these numbers, it is important to realize that not all crops need animal pollination. Some crop plants are wind-pollinated (e.g., staple grains such as rice, corn, wheat) or self-pollinated (e.g., lentils and other beans), needing no animal pollinators to successfully produce fruits or seeds.

A wide range of animals can be important pollinators (e.g., birds, bats, moths, and flies), but bees are the most important group for most crops. As a result, the InVEST Pollination model focuses on the resource needs and flight behaviors of wild bees. Many people think of honeybees, managed in artificial hives when they think of pollinators, but wild bees also contribute to crop pollination. In fact, for several important crops (e.g., blueberries), native species are more efficient and effective pollinators than honeybees. These native bees, in addition to feral honeybees living in the wild, can benefit crops without the active management of captive hives. This is the pollination service associated with habitat conservation. For bees to persist on a landscape, they need two things: suitable places to nest, and sufficient food (provided by flowers) near their nesting sites. If provided these resources, pollinators are available to fly to nearby crops and pollinate them as they collect nectar and pollen.

The model translates land cover into an index of suitability (0-1) for bees to create a pollinator source map. Higher scores indicate sources of greater relative bee abundance. To calculate the index, the model assumes that bees require two types of limited resources to persist on a landscape - nesting substrates and floral resources. Given an input of land cover that describes the landscape, various suitability values of each LULC class are assigned based on their ability to provide these resources.

The Pollination model then uses the nest supply index to estimate the pollinators visiting crop fields. It assumes the supply from nearby parcels contributes more than those farther away. Additionally, this model incorporates the potential use of managed bees into a yield index. With information on the location of crops and their dependence on pollinators, the model uses a simple yield function to project how wild pollinator abundance in agricultural areas and the use of managed bees contribute to an index of crop yields.

The abundance indices for peak-pollinating bees were calculated as follows.

$$P_{x\beta} = N_j \cdot \frac{\Sigma_{m-1}^{M} F_{jm} e^{\frac{-D_{mx}}{\alpha_\beta}}}{\Sigma_{m-1}^{M} e^{\frac{-D_{mx}}{\alpha_\beta}}}$$

$P_{x\beta}$ is an index of species richness for raster cell x and species β. N_j is the nesting fitness of type j in the LULC plot, F_j is the relative number of floral volunteers produced at LULC type j, Dmx is the Euclidean distance between cells m and x, and α_β is the expected foraging distance of pollinators.

Table 6 Data requirement of the InVEST pollination model

Data	Type	Description
Land use/land cover	Raster	Map of land use/land cover codes
Watersheds	Vector/ polygon	Map of the boundaries of the watershed(s) over which to aggregate the model results
Guild Table	CSV	A table mapping each pollinator species or guild of interest to its pollination-related parameters
Area of Interest	Vector/ polygon	A map of areas over which to aggregate and summarize the final results
Biophysical Table	CSV	A table mapping each LULC code to biophysical properties of the corresponding LULC class

4.8 Carbon storage and sequestration

Ecosystems regulate the Earth's climate by adding and removing greenhouse gases such as carbon dioxide from the atmosphere. The total amount of carbon stored in forests, grasslands, peat bogs, and other terrestrial ecosystems far exceeds that of the atmosphere. Ecosystems release this carbon stored in wood, other biomass, and soil as carbon dioxide into the atmosphere, which in turn causes changes in the climate.

In addition to storing carbon, many systems continue to accumulate carbon in plants and soils over time, thereby 'sequestering' additional carbon. Significant amounts of carbon dioxide can be released through fire, disease, or vegetation conversion (e.g., land use and land cover changes). The way we manage terrestrial ecosystems is therefore critical to regulating our climate.

Managing carbon storage at the landscape scale requires information on the spatial distribution and amount of carbon stored, how much carbon has been stored or lost over time, and how land use affects carbon storage and storage over a time period. The InVEST model uses LULC maps as well as the amount of timber harvested, the rate of degradation of harvested products, and the carbon stocks of four carbon pools (above-ground biomass, below-ground biomass, soil, dead organic matter) to estimate the amount of carbon currently stored in the landscape or sequestered over time. With the market or social value of the stored carbon and its annual rate of change, as well as discount rate data, the value of ecosystem carbon sequestration services to society can be estimated.

Carbon storage on a land parcel largely depends on the sizes of four carbon pools: aboveground biomass, belowground biomass, soil, and dead organic matter. The InVEST Carbon Storage and Sequestration model aggregates the amount of carbon stored in these pools according to land use maps and classifications provided by the user. Aboveground biomass comprises all living plant material above the soil (e.g., bark, trunks, branches, leaves). Belowground biomass encompasses the living root systems of aboveground biomass. Soil organic matter is the organic component of soil and represents the largest terrestrial carbon pool. Dead organic matter includes litter as well as lying and standing deadwood.

Using maps of LULC classes and the amount of carbon stored in carbon pools, this model estimates the net amount of carbon stored in a land parcel over time and the market value of the carbon sequestered in the remaining stock. Limitations of the model include an oversimplified carbon cycle, an assumed linear change in carbon sequestration over time, and potentially inaccurate discounting rates. Biophysical conditions important for carbon sequestration such as photosynthesis rates and the presence of active soil organisms are also not included in the model.

The InVEST model calculates carbon stocks for different periods and different land types based on the data of different land-use types and their corresponding carbon density of four major carbon pools: aboveground biomass, belowground biomass, soil, and dead organic matter.

$$C_z = C_{above} + C_{below} + C_{dead} + C_{soil}$$

$$E_i^{CF} = S^{CF} * v_i$$

Where C_z is the total carbon stock, C_{above} is the aboveground carbon stock, C_{below} is the belowground carbon stock, C_{dead} is the dead organic matter carbon stock, and C_{soil} is the soil carbon stock. Each carbon stock is obtained by multiplying carbon density with the area.

Table 7 Data requirement of the InVEST carbon storage and sequestration model

Data	Type	Description
Land use/land cover	Raster	Current and future maps of land use/land cover codes
Carbon Pools	CSV	A table that maps each LULC code to carbon pool data for that LULC type
Area of Interest	Vector/ polygon	A map of areas over which to aggregate and summarize the final results
Carbon price	/	

5. Analysis of residual emissions

The types of pollutants in this section include air pollutants (ammonia nitrogen, nitrous oxide, methane), water pollutants (chemical oxygen demand, ammonia nitrogen, total nitrogen, total phosphorus), solid waste (unused straw, waste animal manure), and carbon dioxide. Methods to be used for accounting specific substance masses of the different pollutants are as follows.

Water pollutants (chemical oxygen demand, ammonia nitrogen, total nitrogen, total phosphorus): the coefficient method will be used to account for the physical mass of water pollutant emissions based on the emission coefficients taken from the *Handbook of Agricultural Pollution Source Production and Emission Coefficients* published by the Ministry of Ecology and Environment of the People's Republic of China in 2021, within the listed amount of pollutants in plantation and farming investigated.

Atmospheric pollutants (ammonia nitrogen, nitrous oxide, methane): The coefficient method will be used to account for the material quantities of emissions of atmospheric pollutants based on the emission coefficients of different types of planting and breeding types reported in the literature and the number of different types of planting and breeding investigated. The emission coefficient is mostly taken from the *Handbook of Agricultural Pollution Source Production and Emission Coefficients*, same as the water pollutants.

Solid waste (unused straw, waste animal manure): questionnaire method will be used to investigate the quantities of unused straw and animal manure, etc.

Carbon dioxide: the life cycle assessment method will be used to account for life cycle carbon dioxide emissions across the value chain.

The different pollutant types will be converted into standard air or water pollutant substance equivalents, and then the economic value of the pollutants will be accounted for in accordance with the provisions of the *Yunnan Environmental Protection Tax Standard*, quantifying the environmental cost of the pollutants.

6. Analysis of changes in human capital

The scope of human capital includes the quantity and quality of the workforce, the skills training of the workforce, the health of the workforce, and the health impact of agricultural products on consumers.

6.1 Quantity and quality of workforces

The quantity and quality of labor are proxied by the number of people participating in the labor force and the level of education of the labor force, respectively. As the value of labor at different levels of education varies, we use the wage levels of different workforces to reflect the value corresponding to the quantity and quality of the workforce. The specific accounting methods for the value corresponding to the quantity and quality of labor in the system are as follows:

$$\mathrm{L} = \sum_{i=1}^{n} (P_i \times T_i)$$

Where L is the value of the labor force, i is the i^{th} labor force, P_i is the wage level of the i^{th} labor force and T_i is the hours worked by the i^{th} labor force. The hourly wage levels for different levels of education are shown in the table below and other information was obtained from the field survey.

Table 10 Hourly wages for different education levels (Wang et al., 2019)

Education Level	Hourly wage (yuan/hour; 2004 prices)
Primary school or below	9.9
Lower Secondary	10.8
High School	11.5
University and above	16.7

The workforces needed in different farming categories in the future is projected based on the scale of different farming categories in different scenarios and current workforces in different farming categories collected in the survey. It is assumed that in the future the work forces in different farming categories would increase proportionally with the farming scale. The education level of the workforces is assumed to increase proportionally with the education level increase of the country. The salary of the workforces is also assumed to increase in accordance with the country.

6.2 Skills training of workforces

As the value of workforce skills training is difficult to quantify, it is described using a combination of qualitative and quantitative methods, with a survey to obtain information on the type, frequency, length, and level of training received by the workforces.

The change of skills training of the workforce will be projected based on the current skills training of workforces collected in the survey as well as the change of workforce depicted in 6.1 in different scenarios. It is assumed that the training of workforces will increase in a linear manner and all workforces will get proper training until 2050.

6.3 Health implications

6.3.1 Occupational exposure

Occupational exposure is defined as the contact between agents (environmental elements with harmful substances) and targets. In our case, agents include air, water, and soil that contain potentially harmful substances resulting from agri-chemical inputs into the soil and disseminated into the environment. Agents encompass all range of agricultural practitioners such as farmers and employees in beef cattle breeding and conventional cultivation that work strictly in an agricultural setting. Therefore, we have selected soil exposure as the primary route of contact in the assessment process. The source of the harmful substances contains agricultural chemicals, such as insecticide, herbicide, fungicide, and chemical fertilizers, being applied in the farming process. Contact may take place at any exposure surface including mouth, skin, and eyes over an extended working period and at an exposure frequency.

Lifetime theoretical maximum contributions (LTMCs) of the chemicals are computed from human major exposure routes at maximum legal exposures, which include occupational (i.e. farmland, cattle pens, etc.) soil, water, and air. The worldwide average human life expectancy is assumed to be 70 years, and the lifetime exposure to pesticides is considered only for working adults. The LTMC computed from occupational soil exposure is expressed in the following equations and includes ingestion, inhalation, and dermal contact.

$$LTMC_{ingestion} = RGV \times CF \times EF \times (IR \times ED)$$

LTMC$_{ingestion}$: LTMC calculated from occupational ingestion (kg)

RGV: Chemical concentration value in the soil (mg/kg), which can be obtained from the use of pesticides and fertilizers and their corresponding coefficients going to the soil.

IR: Ingestion rate of soil for adults (1.0 × 10.4 kg/day or 0.1 mg/day) (ATSDR, 2005)

EF: Exposure frequency (days/yr, to be calculated based on field survey)

ED: Exposure duration (24 yr) (USEPA, 2002)

CF: Conversion factor (1.0 × 10^{-6} kg/mg)

$$LTMC_{inhalation} = \frac{RGV \times CF \times EF}{PEF} \times (IhR \times ED)$$

LTMC$_{inhalation}$: LTMC calculated from soil dust inhalation (kg)

$RGV, CF, and\ EF$: inherited from previous equation

PEF: Particulate emission factor (1.32 × 109 m^3/kg) (USEPA, 1996)

IhR: Inhalation rate for adults (20.0 m^3/day) (USEPA, 1986)

$$LTMC_{dermal} = RGV \times AF \times CF \times EF \times (SF \times SA \times ED)$$

LTMC$_{dermal}$: LTMC calculated from soil dermal contact (kg)

$RGV, CF, and\ EF$: inherited from previous equations

SF: Skin adherence factor for adults (7.0 × 10^{-8} kg/cm^{-2}) (ATSDR, 2005)

SA: Exposed skin area for adults (4656 cm^2) (USEPA, 1997)

AF: Bioavailability factor (or dermal absorption factor) (0.1 unit less) (ATSDR, 2005)

Thus, the LTMCs computed from the soil exposure from previous equations are combined as follows to yield the total soil LTMC$_{soil}$.

$$LTMC_{soil} = LTMC_{ingestion} + LTMC_{inhalation} + LTMC_{dermal}$$

The occupational exposure in different scenarios is simulated based on the current pesticide use in different crops categories, future crop's structure, and pesticide decrease rate in different scenarios settings. The human health of occupational exposure in different scenarios will be calculated according to the equations in this section.

6.3.2 Water exposure downstream

Water exposure because of pesticide and fertilizer use is calculated based on the use of pesticides and fertilizers (collected in the survey data) and their corresponding coefficients going to the water. Also, the water pollutions from mismanagement of manure residues are calculated based on the quantities of mismanaged manure (collected in the survey data) as well as its coefficient on the water. All the pollutants entering into water bodies are classified based on their chemical composition. And the health impact because of water exposure is calculated based on those chemicals. The health impact will be calculated using the Impact 2002+ method integrated in Simapro Software and expressed in DALY.

The health impact in different scenarios is also projected based on the pesticides and fertilizers used and mismanaged manure residues set in different scenarios. The Impact 2002+ method integrated into Simapro Software will be employed to calculate the health impact from water exposure downstream.

6.3.3 Consumption of agricultural products

The health effects related to the consumption of agricultural products are accounted for according to the residues of pesticides and other harmful substances in the product, as described below.

The lifetime theoretical maximum contributions (LTMC) computed from the agricultural foods' exposure is expressed in the equation below, and only ingestion was considered. The consumption rates of the most commonly consumed agricultural foods were estimated. The agricultural foods' consumption rates were estimated by taking average values from other worldwide nations.

$$\mathrm{LTMC}_{food} = \sum_{i=1}^{n} (MRL_i \times CoF \times ED \times CR_i)$$

LTMC_{food}: LTMC calculated from agricultural foods (kg)

MRL_i: Pesticide agricultural food maximum residue level in food i (mg/kg)

CoF: Conversion factor (1.0×10^{-6} kg/mg).

ED: Exposure duration (70 yr)

CR_i: Consumption rate for agricultural food i (kg/year)

To quantify the human health impacts of maximum legal exposure to pesticides, the health risk characterization factor (DALYs) was employed to convert the LTMC into the human health damage metric: DALYs per million populations. The human health damage factor (DALYs per incidence) is based on cancer and noncancer damage resulting from human exposure to pesticides via ingestion of soil, water, and foods that include carcinogens and noncarcinogens. Health damage, incidence rate, and toxic effect of chemicals were derived from lognormal dose-response curves (Huijbregts et al., 2005) while other studies (Pennington et al., 2002; Crettaz et al., 2002) applied linear dose-response curves when below the effect dose affecting 10% of the individuals (ED10). Cancer and noncancer incidences for selected pesticides are weighted according to their respective severity and expressed by a loss of (healthy) lifetime expressed in DALYs (Fantke and Jolliet, 2016; Huijbregts et al., 2005; Li, 2018). Aggregated cancer and noncancer health damage for the pesticides in human major exposure routes were derived using the following health risk characterization factor equation:

$$\mathrm{CF} = \sum_{i=1}^{n} (LTMC_{food} \times P \times (DRSF_{cancer} \times DF_{cancer} + DRSF_{non-cancer} \times DF_{non-cancer}))$$

CF: Health risk characterization factor (DALYs per million population, or DALYs)

$LTMC_{food}$: LTMC computed from the food intake

P: Population (1.0×10^6, or million)

$DRSF_{cancer}$ and $DRSF_{non-cancer}$: Dose-response slope factors (Fantke and Jolliet, 2016) for cancer and noncancer (incidence/kg; DRSFs of pesticides in this study were taken from Rosenbaum et al., 2015)

DF_{cancer}: Damage factor for cancer (11.5 DALYs per incidence) (Fantke and Jolliet, 2016) (Huijbregts et al., 2005)

$DF_{non-cancer}$: Damage factor for noncancer (2.7 DALYs per incidence) (Fantke and Jolliet, 2016) (Huijbregts et al., 2005)

The economic value loss because of pesticides in food intake is calculated according to the equation below.

$$Loss_{pesticide} = CF \times 10^{-6} \times VSL$$

$Loss_{pesticide}$: Economic value loss because of pesticides in food intake

CF: Health risk characterization factor (DALYs per million population, or DALYs)

VSL: Value of statistical life

7. Analysis of changes in social capital

The scope of accounting for social capital comprises women empowerment and social institution. Due to the lack of quantitative tools, a qualitative description with basic data analysis is used to provide information on the agricultural value chain in Tengchong County on the two aspects, and to analyze the role played by the agricultural system.

7.1 Women empowerment

Women empowerment data mainly include women workforces in the agri-food system, the education level of women workforces, and the salary of women workforces. Based on the women empowerment data in the current agri-food system in Tengchong County collected in the survey and the expected agri-food system development in different scenarios, we can project the quantity and distribution of women's workforces in different sectors. Based on the education development trajectory and salary change trend of different education levels and different sectors, we could project the education levels and income of the women forces in different scenarios.

7.2 Social institutions

Social institutions mainly refer to the rural cooperatives for farming in the villages. Based on the data of different categories of farming and corresponding rural cooperatives, we project that the number of cooperatives of different farming categories would increase in a linear pattern, and all farming entities would join rural cooperatives until 2050. Also joining rural cooperatives would bring economic benefits to the entities. It is assumed that a net 5% increase in the sale price of the products could be achieved if the entities join the rural institutions.

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