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The Economics of Ecosystem and Biodiversity (TEEB)

Promoting a Sustainable Agriculture and Food Sector (China)

Synthesis report

of

the application of TEEBAgriFood assessment to the National

"Green is Gold" Practice Innovation Base – Tengchong, Yunnan

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Executive summary

The TEEBAgriFood application in Tengchong

The Economics of Ecosystems and Biodiversity (TEEB) is a key international program aimed at understanding the importance of nature and incorporating the values of biodiversity and ecosystem services into decision making at all levels. The TEEB for Agriculture and Food (TEEBAgriFood) program applies the principles and methods of TEEB to the agricultural sector. It uses a systems approach to conduct economic evaluations of the “ecosystem-agriculture-food” system, revealing its positive and negative externalities, and enhancing policymakers’ understanding of the relationship between agriculture, the environment, and society.

This TEEBAgriFood Tengchong assessment was carried out under the guidance of the TEEB office of the United Nations Environment Programme (UNEP), a national Project Steering Committee chaired by the Ministry of Ecology and Environment and was funded by the European Union as part of a five-year project in China, Brazil, India, Mexico, Indonesia. Thailand and Malaysia. The study aims to assess the full costs and benefits on nature, economy and society of different agricultural pathways in Tengchong, over the years 2025, 2035 and 2050. Such costs and benefits include impacts on human health, women’s empowerment, quantity and quality of jobs, air, water and greenhouse gas emissions, and ecosystem services such as soil health, carbon sequestration, water quality and provisioning of agricultural inputs.

Tengchong was selected as the TEEBAgriFood focus due to its full-scale landscape ecosystem, rich local resources, potential of influencing policy and management decisions, level of government support, international comparative potential. The aim is to provide policy support for the ecological and green development and effective transformation of the “Green is Gold” concept in the region and to provide reference for other regions in the promoting the construction of ecological civilization in China. Tengchong City is actively exploring the development of eco-friendly agriculture and promoting the integration of agriculture and tourism to effectively transform "the Green" into economic benefits. Tengchong is located in the western part of Yunnan Province and is under the jurisdiction of Baoshan City. The region is known for its unique cultural heritage as it is home to a number of ethnic minority groups, and also has a long history of sustainable agriculture.

The study considers combinations of different agricultural policies, such as chemicals use reduction, under-canopy plantation, combined planting-breeding, and greenhouse gas emissions reduction and control, taking into account both visible and invisible costs and benefits, and the interests of the current and future generations. The TEEBAgriFood Evaluation Framework analyzes the costs and benefits generated by the development scenarios from the perspective of four types of capital: natural capital, produced capital, human capital, and social capital.

By disclosing the interdependencies of the components of agri-food systems and balancing the trade-offs among them, the study results can reveal the paths of effective Green to Gold transformations, support the formulation of sustainable agriculture policies, and address the goals of the China Biodiversity Conservation Strategy and Action Plan (2011-2030) to reduce the impact of agriculture on biodiversity and promote the restoration of degraded landscapes.

Policy Context

The global food systems transformation is a global initiative that aims to transform the way food is produced, distributed, and consumed to achieve sustainable development. As the TEEBAgriFood study in Tengchong focuses on promoting sustainable agriculture and food production in China, it links closely with this agenda as this aim is a key component of the plan. By providing an economic valuation of ecosystem services and identifying sustainable and economically viable livestock and plantation modes, the assessment supports a sustainable transformation of the food and agricultural system. The study also provides policy recommendations that support the achievement of several SDGs that are part of the food systems transformation agenda. The Kunming-Montreal Global Biodiversity Framework on the other hand, is a global initiative that aims to promote the conservation and sustainable use of biodiversity. The TEEBAgriFood assessment in Tengchong focuses on maintaining biodiversity and restoring degraded landscapes and provides policy recommendations that support the conservation and sustainable use of biodiversity in Tengchong.

Furthermore, in the Chinese policy context, the study also aligns with a number of policies and initiatives to promote sustainable agriculture, including the National Plan for Sustainable Agriculture Development (2015-2030) and the National Action Plan for Biodiversity Conservation (2011-2020), that the Chinese government has implemented. More broadly, the study is aligned with the Overall Plan for the Reform of the Ecological Civilisation System (2015) and the State Council issued "Opinions on Establishing and Improving the Mechanism for Realizing the Value of Ecological Products," (2021) which calls for "promoting the application of ecological product value accounting results in government decision-making and performance evaluation." As such, the TEEBAgriFood assessment is well-aligned with the international and Chinese policy context, as it provides valuable insights into the economic benefits of ecosystem services in agriculture and supports the development of sustainable agricultural policies in China.

Scenarios and Variables Assessed

One of the key components of the TEEBAgriFood study is the evaluation of different scenarios and variables that affect the sustainability of the agriculture and food sector. Different scenarios and variables were analyzed to understand the economic benefits of ecosystem services in agriculture, where the impact of policy, climate change, population change, and urbanization on agriculture were considered. Sustainable and economically viable livestock and plantation modes were identified that can support sustainable agriculture and food production in Tengchong. Based on key findings, the study proposes recommendations to promote sustainable and economically viable livestock and plantation modes to enhance the economic valuation of ecosystem services, and to strengthen policy linkages that support sustainable agriculture and food production in China.

The assessment considers three scenarios: Business as Usual (BAU), Pessimistic, and Optimistic. The BAU scenario represents the continuation of current trends and practices, while the Pessimistic and Optimistic scenarios represent alternative pathways that reflect different levels of ambition and policy interventions. The study also considers various variables, such as land use, crop yields, livestock production, water use, and greenhouse gas emissions, to evaluate the economic, social, and environmental impacts of different scenarios. In this way, decision-makers are provided with an understanding of the trade-offs and synergies between different policy options and their impacts on the sustainability of the agriculture and food sector.

The overall scenario setting for the TEEBAgriFood Tengchong City demonstration evaluation is shown in Table 4.1, which considers the combination of three policy paths ("baseline," "positive," and "negative") and two climate change paths (RCP4.5 and RCP8.5) at three time points (2025, 2035, and 2050), and simulates and quantifies the natural, economic, and social costs and benefits (including visible and invisible ones) brought by future policy implementation. By comparing the scenarios, this study supports Tengchong City's more systematic and comprehensive understanding of the possible impacts of policy implementation, incorporates relevant considerations into the formulation of the next five-year plan, provides a basis for the formulation of sustainable policies in Tengchong City, and provides references for other regions.

Scenario 1	Scenario 2	Scenario 3
GHG moderate emission pathway (RCP4.5) + BAU (2025, 2035, 2050)	GHG moderate emission pathway (RCP4.5) + Optimistic (2025, 2035, 2050)	GHG moderate emission pathway (RCP4.5) + Pessimistic (2025, 2035, 2050)
Scenario 4	**Scenario 5**	**Scenario 6**
GHG high emission pathway (RCP8.5) + BAU (2025, 2035, 2050)	GHG high emission pathway (RCP8.5) + Optimistic (2025, 2035, 2050)	GHG high emission pathway (RCP8.5) + Pessimistic (2025, 2035, 2050)

Table 1: Project scenario setting (4.1 in the synthesis report)

Key findings and recommendations

The following key findings were made in the Tengchong TEEBAgriFood study which are described in detail in the report:

1. Tengchong City is rich in the values of ecosystem regulation services such as water regulation and purification, soil conservation, and carbon sequestration, and they are insensitive to different agricultural development pathways. This indicates that the ecosystems in Tengchong City are resilient enough to resist exogenous disturbances. Natural capital is one of the foundations of local economic and social development. For

years, the forest cover in Tengchong has been maintained above 75%, which is related to the long-term protection of natural ecosystems by national and local policies.

2. Tengchong City's forest system has a strong carbon sink function, with carbon sequestration of 37.5 million tons of CO_2 equivalent in 2020. In contrast, the greenhouse gas emissions from Tengchong City's agricultural system are relatively small: in 2020 agriculture GHG emissions account for about 2.67% of its annual carbon sequestration; by 2050, the proportion is expected to be around 5%. Different agricultural development paths will not change the fact that Tengchong functions as a net carbon sink.

3. Nitrogen and phosphorus emissions from water pollution in agricultural systems need to be taken seriously. The nitrogen consumed by the water purification function of the natural ecosystem accounts for less than 7% of the total nitrogen discharge, and the phosphorus consumed accounts for less than 25% of the total phosphorus discharge. This indicates that the water pollution caused by the agro-food system far exceeds the purification capacity of the natural ecosystem itself. Therefore, the management of manure wastewater from beef cattle breeding should be strengthened, and the leaching of fertilizers should be further reduced.

4. Comparing the different agricultural development paths, it is found that the total net value of the natural, economic, and social effects of the "positive" development path is higher than that of the "baseline" and the "negative" paths. For example, by 2050, the total net value of the "positive" pathway is 7% higher than that of the "baseline" scenario and 10% higher than that of the "negative" scenario. From a health point of view, the "positive" development path leads to less negative impacts on human health, especially in the long term.

5. Analyzing the decision-making of farmers, who are the main actors in the transformation of the agrifood system, it was found that choosing a more ecologically friendly way of farming does not entail more economic pressure than other ways of farming when only considering farming expenditures and revenues; and that in the long run, their net income can still increase by a small amount.

Furthermore, based on the key findings, the following recommendations are proposed:

- Integrating the whole systems thinking and accounting the market-invisible costs and benefits to support sustainable agriculture development and the country’s Green to Gold transformation.

- Agricultural water pollution discharge is a limiting factor for local development and should be controlled by multiple measures.

- Agricultural emissions management must be carefully planned for to support the local development agenda and the national dual-carbon strategy.

- Realizing the potential of ecotourism requires carefully managing the development and conservation nexus and taking a multi-stakeholder approach.

In addition, promoting sustainable and economically viable livestock and plantation modes that can support sustainable agriculture and food production is advised. In order to achieve better coordination of economic development, people's livelihood, and ecological protection, three suggestions are made. Firstly, policies should consider specific conditions in different regions and plan accordingly to make sure the disturbances from eco-tourism will not exceed the threshold of ecosystems. Secondly, once developed, it is necessary to educate tourists on environmental ethics and minimize the environmental impact of the tourism process. Thirdly, for natural resources that are constrained from tourism or other development, such as Tengchong that provides biodiversity conservation and carbon sequestration services, government at national level should take a holistic view and mobilize financial support safeguarding local development, such as through the fiscal transfer payment system.

Policy mainstreaming roadmap

The policy mainstreaming roadmap of the TEEBAgriFood project is structured around five pillars to enhance the science-policy interface.

Pillar 1: National and subnational level policy engagement. Customized policy recommendations are drafted by the Institute of Geographic Sciences and Natural Resources Research (IGSNRR) and submitted to the General Office of the State Council through the Chinese Academy of Sciences (CAS).

Pillar 2: Sub-national level policy engagement. As 2024 to 2025 is the key period for the formulation of the 15th Five-Year Plan across the country (2026-2030), national, provincial, and local level governments will start drafting the Plan for National Economic and Social Development as well as respective sectoral five-year plans, guided by a state-level document issued by the Political Bureau of the Communist Party of China (CPC) providing suggestions on the strategic direction. Recommendations from the study will be presented to the municipal government of Tengchong to support the drafting of the plans.

Pillar 3: Key stakeholder engagement. Stakeholder consultations and PSC meetings have been taking place since the project inception.

Pillar 4: Other dissemination events. China has hosted the CBD COP15 as well as many other sub-national, national, and international events, key messages and findings derived from the TEEBAgriFood assessment have been widely disseminated which are an important means of infusing the recommendations to a wider range of audiences including decision-makers.

Pillar 5. Contributions to the implementation of the Kunming-Montreal Global Biodiversity Framework. The scope of the TEEBAgriFood project in China through the lens of the Tengchong study fits well in the scope of the Kunming-Montreal Global Biodiversity Framework (GBF) and can support its implementation in China in multiple dimensions. In turn, the Framework could also provide insights for realizing these suggestions. The TEEB approach serves as an example of the CBD's long-term strategic approach to policy mainstreaming and how to incorporate natural capitals thinking into the Framework. The TEEBAgriFood framework for assessment focuses particularly on the major driver of biodiversity loss and aims to re-orient the undesirable agricultural activities that have exacerbated biodiversity loss and ecosystems degradation. Among the 23 action-oriented global targets for urgent action over the decade to 2030, several are related to the Tengchong study and the derived recommendation, including:

- Target 14 on the integration of biodiversity and its multiple values into policies
- Target 10 on increasing the application of biodiversity friendly agriculture practices
- Target 7 on reducing excess nutrients
- Target 19 on increasing financial support
- Target 3, that is to ensure any sustainable use is fully consistent with conservation outcomes
- Target 16 on encouraging and enabling people to make sustainable consumption choices

Pillar 6. Public dissemination and social media outreach. Efforts have been made to publicize the concept of the TEEBAgriFood framework and key information from the assessment through social and conventional media.

The use of study results to inform decision making and raise awareness at various levels and through multiple channels and platform will encourage the use of information from transformative and transdisciplinary science-policy interface studies in the communication, education, awareness-raising and uptake of the diverse values of biodiversity and nature's contribution to people.

1. Introduction

Agriculture is highly dependent on nature, especially on well-functioning ecosystems. Globally, agriculture is responsible for 80% of deforestation, 29% of GHGs, 70% of freshwater use; drivers linked to food production cause 70% of terrestrial biodiversity loss, and 50% of freshwater biodiversity loss (WWF, 2020). In addition, agriculture is a significant source of employment, livelihoods, and social and cultural well-being, and also determines human health and nutrition. Developing sustainable food and agricultural systems is considered one of the important ways to address these challenges, providing the possibility to feed the growing global population while protecting nature.

The sustainable transformation of the food and agricultural system needs to consider a range of impacts, but the environmental and social impacts of the system have not been fully considered and valued. For example, the contributions of natural systems such as freshwater supply, climate regulation, and insect pollination to agriculture, as well as downstream water pollution caused by the use of fertilizers or pesticides. Some of the externalities of the agricultural system are economically visible and can be reflected in social accounting or corporate accounts, but many more impacts are invisible and difficult to value. Decision-makers often focus only on those parts that are easy to identify, trade, and monetize, even if evidence-based decision-making often only considers the extensively studied parts of this complex system, while ignoring the various linkages and feedbacks between them. This has led to more and more policies, plans, and strategies that solve specific problems with "isolated" solutions, but led to unexpected consequences, consequences, trade-offs, and impacts.

The Economics of Ecosystems and Biodiversity (TEEB) is a key international program aimed at understanding the importance of nature and incorporating the values of biodiversity and ecosystem services into decision-making at all levels. It is led by the United Nations Environment Programme (UNEP) and was launched at the G8+5 Environment Ministers Meeting in Potsdam in 2007. TEEB aims to reveal the extensive benefits that ecosystems and biodiversity provide from an economic perspective through structured assessments. Its essence is to provide a tool for public and private sector decision-making to fully consider their impacts on nature in policy formulation.

The TEEB for Agriculture and Food (TEEBAgriFood) program applies the principles and methods of TEEB to the agricultural sector. It uses a systems approach to conduct economic evaluations of the "ecosystem-agriculture-food" system, revealing its positive and negative externalities, and enhancing people's understanding of the relationship between agriculture, the environment, and society. The "Economics of Ecosystems and Biodiversity: Promoting Sustainable Agriculture and Food Systems" project (hereinafter referred to as the "TEEBAgriFood project" or "this project") is being implemented in seven countries: Brazil, China, India, Indonesia, Malaysia, Mexico, and Thailand. Through demonstration evaluations, the project supports the development of sustainable agricultural policies to maintain biodiversity and restore degraded landscapes. The project activities are funded by the European Union and are carried out under the guidance of the TEEB office of the United Nations Environment Programme (UNEP).

This report is a comprehensive presentation of the results and policy implications of the demonstration evaluation of the TEEBAgriFood project in China. The previous "Report on the

Definition of Project Scope and Scenario Setting" introduced the basic situation of the TEEBAgriFood project demonstration area in China and the future development scenario under driving factors such as policy, climate change, population change, and urbanization. The "Report on Project Data and Methodology" provided an overview of the data and methods used in the TEEB agricultural and food system assessment in Tengchong, while the "Preliminary Results Report" provided full findings of the TEEBAgriFood Tengchong assessment.

2. The policy context

With the rapid growth of the Chinese economy, there is increasing emphasis on addressing environmental issues. "Ecological civilization" draws on the philosophical wisdom of ancient China, with the vision of pursuing harmonious coexistence between humans and nature, replacing the approach of blind pursuit of economic growth. Since 2012, China has proposed to integrate the construction of ecological civilization into all aspects and processes of economic, political, cultural, and social development. In 2018, "ecological civilization" was written into the national constitution, becoming the ideological framework for national environmental policies, laws, and education, and also the overall development strategy of the country.

The concept of "lucid waters and lush mountains are invaluable assets" (also known as "Green is Gold") is an important ideological foundation for promoting the construction of ecological civilization. "Lucid waters and lush mountains" can be understood as a well-structured and functional ecosystem, while "invaluable assets" refer to various types of wealth and well-being that meet human needs. It expresses the value orientation of respecting nature, adapting to nature, and protecting nature, interprets the natural capital view of ecological economy, and promotes the exploration of new paths to achieve coordinated and symbiotic development and protection across the country.

Since 2017, the Chinese Ministry of Ecology and Environment has been creating "Green is Gold" practice innovation bases nationwide[1], encouraging local areas to actively explore typical practices, experiences, and effective paths for developing ecological economy and promoting green development based on ecological resources, and organizing timely tracking, evaluation, summary, and national promotion. By the end of 2022, a total of 187 practice innovation bases had been established across the country.

The work of the TEEBAgriFood project in China is based on stakeholder consultations and is carried out under the guidance of the project steering committee (referred to as the "PSC" below). The PSC is chaired by the Ministry of Ecology and Environment and includes representatives and experts from the Ministry of Agriculture and Rural Affairs, the Chinese Academy of Sciences, the United Nations Environment Programme, and demonstration provinces and cities. In July 2020, the PSC selected the national "Green is Gold" practice innovation base Yunnan Province's Tengchong City as the TEEBAgriFood evaluation demonstration area, taking into account its full-scale landscape ecosystem and rich local germplasm resources, , potential of influencing policy and management decisions, level of government support, and international comparative potential. The

[1] The construction and management protocol of the Green is Gold practice innovation base can be found at: https://www.mee.gov.cn/xxgk2018/xxgk/xxgk03/201909/W020190919344656829212.pdf

aim is to provide policy support for the ecological and green development and effective transformation of the "Green is Glod" in the region and to provide reference for other regions.

3. Project demonstration site

3.1 Overview

Tengchong City is located in the western part of Yunnan Province and is under the jurisdiction of Baoshan City, Yunnan Province. It has an area of 5848 square kilometers and an altitude ranging from 930 to 3800 meters. The city has an Indian Ocean monsoon climate with warm winters and cool summers, and an average annual temperature of 15.1℃, average relative humidity of 78%, and average annual rainfall of 1531 millimeters. The terrain is high in the northwest and low in the southeast. The three major river systems of Binglangjiang, Longchuanjiang, and Dayingjiang run from north to south, cutting through the city and forming high and low mountain ranges and river valley basins. The valley area accounts for 16% of the total area, while the mountainous and semi-mountainous areas account for 84%. Tengchong City is an important national ecological functional area with a superior ecological environment, rich species resources, and a forest coverage rate of 75%. The soil types are diverse, the soil layer is deep, and the soil quality is mostly of medium to high fertility.

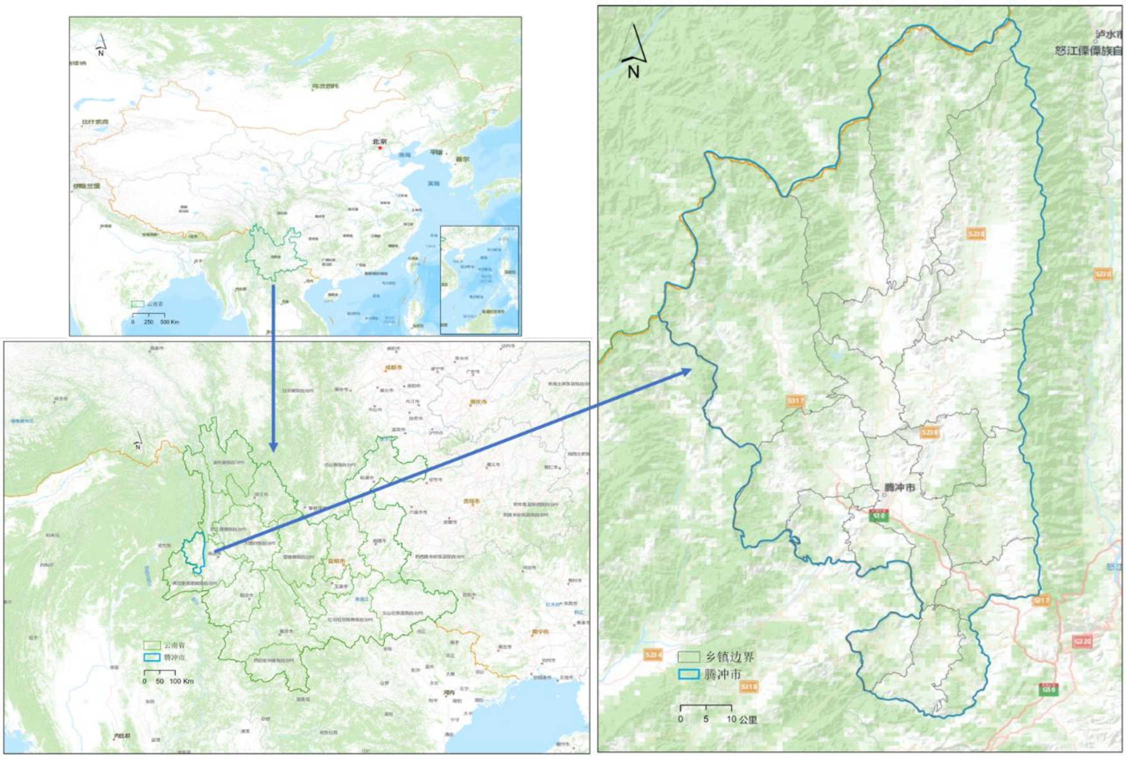

Figure 3.1 Location of Tengchong City

Tengchong City has jurisdiction over 11 towns and 7 townships, inhabited by 25 ethnic groups such as Han, Hui, Dai, Wa, Lisu, and Achang, with a total population of 642,500 people. In 2020, Tengchong City's gross domestic product (GDP) reached 28.235 billion yuan, of which the primary industry contributed 5.5 billion yuan (19.5%), the secondary industry contributed 11.37 billion yuan

(40.3%), and the tertiary industry contributed 11.36 billion yuan (40.2%). The per capita GDP was 43,911 yuan.

Table 3.1 shows a comparison of Tengchong City's economic development level with that of Yunnan Province and the country. It can be seen that Tengchong City is a less developed area with a high proportion of agriculture, and its agricultural GDP ratio is higher than that of Yunnan Province and the country. However, the per capita GDP and per capita disposable income are lower than the levels of the province and the country. At the same time, Tengchong City is also an important demonstration area for practicing the concept of ecological civilization construction. Based on its ecological advantages and the booming healthy industry, Tengchong was selected as the second batch of national "Lucid Waters and Lush Mountains are Invaluable Assets" practice innovation base in 2018.

Table 3.1 Comparison of the economic status of Tengchong with Yunnan Province and the national average in 2020

	GDP (100 Million Yuan)	Primary industry percentage (% GDP)	Secondary industry percentage (% GDP)	Tertiary industry percentage (% GDP)	GDP per capita (Yuan)	Per capita disposable income (Yuan)
Tengchong	282.35	19.5%	40.3%	40.2%	43911	20692
Yunnan	24521.9	14.7%	33.8%	51.5%	51975	23295
National average	1015986.2	7.7%	37.8%	54.5%	72000	32189

*Data sourced from "China Statistical Yearbook 2021" and "Tengchong City Statistical Report 2021"

3.2 The agricultural system and its development

Tengchong City has a diverse and multifunctional agricultural system, with planting (including economic forests) and animal husbandry being the pillar industries of local agricultural development. In 2020, the total agricultural output value of the city was 8.658 billion yuan, and the agricultural added value was 5.525 billion yuan, of which the output value of planting was about 5.591 billion yuan, accounting for about 64.5% of the total output value, and the output value of animal husbandry was about 3.067 billion yuan, accounting for about 35.5% of the total output value. The production of major agricultural products in Tengchong in 2020 is shown in Table 2.1.

Table 3.2 Tengchong City's main agricultural output in 2020

Plantation			
	Produce	Cultivated area (10,000 mu)	Production (t)
1	Staple grains (paddy rice, wheat, maize, etc.)	124.5	431,000
2	Oilseed rape	32.1	50,298
3	Medicinal herbs	Appr. 27.2	约 19,500
4	Tea	15	18,550
6	Xi-hong-ruan rice	0.2	1,000
Livestock			

	Produce	Number raised (head)	Number sold (head)
7	Swine	626,500	805,500
8	Beef cattle	125,200	50,500
9	Goat	71,500	84,300
10	Poultry	1,947,400	3,462,500

During the 14th Five-Year Plan period[2], Yunnan Province will leverage its unique diverse resources to strive to build a world-class "green food brand" and develop high-altitude agriculture[3]. Guided by this, Tengchong City implements the concept of green development. On the one hand, it consolidates and improves traditional industries such as staple food, fruit, and tea, further reduces the use of chemical fertilizers and pesticides, increases the comprehensive development and utilization of straw, strengthens the resource utilization of livestock and poultry manure, builds a good agricultural production environment, reduces agricultural non-point source pollution, develops moderate-scale operations, and builds brands. On the other hand, it focuses on two advantageous characteristic industries: beef cattle breeding and traditional Chinese medicinal herb cultivation, expands production scale, improves the supply level and market competitiveness of green agricultural products.

According to the relevant plans and research by the Agriculture and Rural Bureau of Tengchong City, during the "14th Five-Year Plan" period, the overall scale of the beef cattle industry in Tengchong City will increase significantly: by 2025, the scale of beef cattle farming will increase to 300,000 head. The farming model will vigorously develop standardized farms with a scale of 300 head and family farms with a scale of 50 head. Eco-ranches (2 million mu of plateau eco-ranches) and small-scale farming of less than 10 head will be complementary[4]. In terms of planting, Tengchong City will gradually replace chemical fertilizers with organic or agricultural manure, and adopt biological control measures to prevent and control pests and diseases, reducing the use of pesticides. As a demonstration county of the "Chinese medicinal herbs" industry in Yunnan Province, Tengchong City will also vigorously develop the scale of under-canopy medicinal herb planting. At the same time, considering that intercropping can improve land productivity, intercropping will be promoted for crops; and for the genetically valuable germplasm resource of "Hongxixuan" rice[5], a certain planting area will be maintained.

Meanwhile, Tengchong will strengthen the circular development of planting and breeding industries. In addition to pasture grass and commercial feed, the source of feed for beef cattle breeding will increase the use of agricultural and forestry residues such as corn stover. After treatment, beef cattle manure will be made into organic fertilizer and applied to various crops. In addition, Tengchong will promote the integrated development of agriculture, forestry, and tourism,

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[2] The Five-Year Plan (FYP) is a policy blueprint for China's medium-term social and economic development. The drafting of the first FYP began in 1953, which was the fourth year after the establishment of the People's Republic of China. To date, China has implemented 13 FYPs. Currently, China is in the implementation period of the 14th FYP (2021-2025).

[3] "The Development Plan of Creating a World-Class 'Green Food Brand' in Yunnan Province during the 14th Five-Year Plan Period (2021-2025)"

[4] According to the "Implementation Opinions on the Development of the Beef Cattle Industry with the '1+3+6' Model to Consolidate and Enhance the Poverty Alleviation Effect and Effectively Connect with Rural Revitalization" and survey with the Municipal Bureau of Agriculture and Rural Affairs of Tengchong City.

[5] "Xi-hong-ruan" is a unique rice variety in Baoshan City, known for its small, soft and red grains and excellent quality, and has been rated as one of the "Top Ten Rice Varieties in Yunnan". Its market price is higher than that of ordinary rice.

and promote the development of eco-ranches, tea gardens, and understory plantations for leisure tourism[6].

According to local land use regulations, Tengchong City will adhere to the relevant requirements of the national spatial planning[7], and strictly implement the ecological protection red line and the permanent basic farmland control line. The ecological protection red line refers to areas with extremely important ecological functions, extremely fragile ecology, and potential important ecological value that must be strictly protected; within the ecological protection red line, human activities are generally prohibited in the core protection zone of nature reserves, and development and production activities are strictly prohibited in other areas. Permanent basic farmland refers to cultivated land that is permanently and specially protected to ensure national food security and the supply of important agricultural products.

3.3 Policy linkages

In 2021, the Communist Party of China (CPC) Central Committee and the State Council issued the "Opinions on Establishing and Improving the Mechanism for Realizing the Value of Ecological Products," which called for "promoting the application of ecological product value accounting results in government decision-making and performance evaluation." As a national innovation practice base for the concept of "Green is Gold", Tengchong City is actively exploring the development of eco-friendly agriculture and promoting the integration of agriculture and tourism to effectively transform "the Green" into economic benefits.

As discussed in section 3.2, during the 14th Five-Year Plan period, Tengchong City has formulated corresponding development plans in the natural resources and agriculture sectors, which are consistent with and support a series of national policies (as shown in Table 3.3). Conducting natural, economic, and social impact assessments for future development, and promoting the application of evaluation results in government decision-making, is a strong support for the "Opinions on Establishing and Improving the Mechanism for Realizing the Value of Ecological Products." This will help Tengchong City to explore effective practices and experiences for transforming "lush mountains and lucid waters" into economic benefits, and share and promote them with other regions in Yunnan Province and the country as a whole.

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[6] Accelerating the Development of the "Big Health" Industry Implementation Plan, Tengchong Municipal CPC Committee, Tengchong People's Government, 2018.

[7] The Guiding Opinions of the Central Committee of the Communist Party of China and the State Council on Coordinating the Planning and Implementation of the Three Control Lines in National Territorial Spatial Planning

Table 3.3 Policies related to agricultural development support in Tengchong City

	Specific policy	Issuer	Time	Related content
Domestic	Overall Plan for the Reform of the Ecological Civilization System	CPC Central Committee, State Council	2015	- Develop the concept of natural values and natural capital. - Establish institutional mechanisms for rural environmental governance and speed up the reduction of chemical fertilizers, pesticides and agricultural films as well as the resourcefulness and harmlessness of livestock and poultry breeding waste.
	Opinions on Establishing a Sound Mechanism for Realizing the Value of Ecological Products	CPC Central Committee, State Council	2021	- Promote the application of the results of ecological product value accounting in government decision-making and performance evaluation. Explore the necessary compensation measures based on the physical quantity and value accounting results of ecological products in the preparation of various plans and implementation of construction projects, to ensure the appreciation and preservation of ecological products.
	Guidance on the Integrated Delineation and Implementation of the Three Control Lines in Territorial Spatial Planning	CPC Central Committee, State Council	2019	- By 2035, through strengthening the implementation and management of land and spatial planning, strict adherence to the three control lines (ecological protection red line, permanent basic farmland, and urban development boundary), and guiding the formation of a scientifically moderate and orderly land and spatial layout system.
	China Biodiversity Conservation Strategy and Action Plan (2011-2030)	MEE	2010	- Promoting the concept and behavioral norms that are conducive to the conservation of biodiversity in the fields of agriculture, forestry, and other areas to ensure the sustainable utilization of biodiversity. - Reduce the impact of environmental pollution, such as agricultural non-point source pollution, on biodiversity.
	National Green Development Plan for Agriculture in the 14th Five-Year Plan	MARA, NDRC, MST, MNR, MEE	2021	- By 2025, the amount of fertilizer and pesticides used will continue to decrease, the level of agricultural waste resource utilization will be significantly improved, and agricultural non-point source pollution will be effectively controlled. - By 2025, the greenhouse gas emission intensity of major agricultural products will be significantly reduced, and the capacity of agriculture to reduce emissions, sequester

				carbon, and cope with climate change will continue to increase.
	The 14th Five-Year Plan for the Development of the Circular Economy	NDRC	2021	- Deepen the development of circular economy in agriculture and establish a circular agricultural production mode.
	Opinions on Accelerating the Development of Under-canopy Economy	State Council	2012	- Adhere to ecological priority and ensure the protection of the ecological environment. - Build a number of large-scale and profitable agroforestry demonstration bases, support leading enterprises and professional cooperatives, gradually form a development pattern of "one county, one industry, one village, one product", enhance farmers' sustainable income, stabilize the output value of agroforestry, and increase the comprehensive income of farmers in forestry. The proportion of agroforestry output value to the total output value of forestry has significantly increased. The priority is to ensure that the ecological environment is protected.
Global	The Effectiveness of China's Implementation of National Autonomous Contributions and New Targets and Initiatives[8]	Submitted by the Chinese Government to the UNFCCC	2021	- Agriculture emissions reduction and efficiency improvement: Promote the reduction and efficiency improvement of chemical fertilizers and pesticides, and implement soil testing and formula fertilization. Promote the integration of agricultural machinery and agronomy for fertilization, and the use of organic fertilizers to replace chemical fertilizers. Promote green and efficient pest control technology models such as ecological regulation, physical and chemical inducement, and biological control. Improve the productivity of livestock and poultry, and improve the treatment and utilization of their waste, reducing greenhouse gas emissions from livestock and poultry breeding. - Promoting high-level protection of the ecological environment: Actively exploring

[8] https://cop23.unfccc.int/sites/default/files/NDC/2022-06/%E4%B8%AD%E5%9B%BD%E8%90%BD%E5%AE%9E%E5%9B%BD%E5%AE%B6%E8%87%AA%E4%B8%BB%E8%B4%A1%E7%8C%AE%E6%88%90%E6%95%88%E5%92%8C%E6%96%B0%E7%9B%AE%E6%A0%87%E6%96%B0%E4%B8%BE%E6%8E%AA.pdf

			the implementation of "nature-based solutions," strengthening ecosystem services and biodiversity conservation, tapping the potential for emission reduction and carbon sequestration, and improving the green development level and climate resilience of key sectors and regions.
The Kunming-Montreal Global Biodiversity Framework	CBD Secretariat	2022	- Action Goal 7: Considering cumulative effects, by 2030, reduce all sources of pollution risks and adverse impacts to levels that are not harmful to biodiversity, ecosystem functions, and services, including: (a) reducing excess nutrient loss to the environment by at least half, including increasing nutrient cycling and utilization efficiency; (b) overall, reducing the risks associated with the use of pesticides and highly hazardous chemicals by at least half, based on science, taking into account food security and livelihoods. - Action Goal 10: Ensure the sustainable management of agricultural and forestry areas, particularly through the sustainable use of biodiversity, including by significantly increasing the application of biodiversity-friendly practices, such as sustainable intensification, agroecology, and other innovative methods, to promote the resilience, long-term efficiency, and productivity of these production systems, promote food security, protect and restore biodiversity, maintain nature's contributions to people, including ecosystem functions and services.

MARA: Ministry of Agriculture and Rural Affairs, China; MEE: Ministry of Ecology and Environment, China; MNR: Ministry of Natural Resources, China; MST: Ministry of Science and Technology, China; NDRC: National Development and Reform Commission, China; UNFCCC: United Nations Framework Convention on Climate Change

4. Scenario setting

4.1 Driver and time point

The driving forces that affect the agricultural system can be divided into two categories: natural environmental factors and social and economic factors. This study focuses on policy factors (see section 3.2 for details) and the effects of non-policy factors such as GDP, population change, and urbanization. In terms of natural environmental factors, the study mainly 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.

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[9] 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 agricultural and forestry policy orientation during the "14th Five-Year Plan" period in Tengchong City, this study sets three policy paths: "baseline," "positive," and "negative." The "baseline" policy path represents the most likely changes in Tengchong's main agricultural industries under existing planning, the "positive" policy path represents a more ecological development path than the "baseline," and the "negative" policy path considers a non-ecological development path. The relevant parameters of the three policy paths are detailed in the next section.

The overall scenario setting for the TEEBAgriFood Tengchong City demonstration evaluation is shown in Table 4.1, which considers the combination of three policy paths ("baseline," "positive," and "negative") and two climate change paths (RCP4.5 and RCP8.5) at three time points (2025, 2035, and 2050), and simulates and quantifies the natural, economic, and social costs and benefits (including visible and invisible ones) brought by future policy implementation. By comparing the scenarios, this study supports Tengchong City's more systematic and comprehensive understanding of the possible impacts of policy implementation, incorporates relevant considerations into the formulation of the next five-year plan, provides a basis for the formulation of sustainable policies in Tengchong City, and provides references for other regions.

Table 4.1 Project scenario setting

[9] Building a moderately prosperous society is a grand strategy since the 1980s aimed at realizing national prosperity and 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 make economic development the center and drive progress in all aspects of society. 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. This is a critical step towards realizing the Chinese dream of national rejuvenation.

Scenario 1	Scenario 2	Scenario 3
GHG moderate emission pathway (RCP4.5) + BAU (2025, 2035, 2050)	GHG moderate emission pathway (RCP4.5) + Optimistic (2025, 2035, 2050)	GHG moderate emission pathway (RCP4.5) + Pessimistic (2025, 2035, 2050)
Scenario 4	**Scenario 5**	**Scenario 6**
GHG high emission pathway (RCP8.5) + BAU (2025, 2035, 2050)	GHG high emission pathway (RCP8.5) + Optimistic (2025, 2035, 2050)	GHG high emission pathway (RCP8.5) + Pessimistic (2025, 2035, 2050)

4.2 Livestock and plantation modes

4.2.1 Livestock

Eco-ranches: Eco-ranches is based on the idea of ecological and circular development, where beef cattle are raised on concentrated and contiguous grasslands while also developing tourism to enhance economic, cultural, and ecological benefits. By combining grass planting and moderate grazing, a "grass + livestock + manure + fertilizer" closed-cycle breeding system is formed, which reduces breeding costs and improves the quality of meat.

Large-scale standardized breeding: Enterprises raise beef cattle in a standardized way with a scale of 300 head per breeding farm. Feed mainly comes from grassland pasture, purchased commercial feed, and agricultural and forestry residues. According to the plan, one beef cattle requires 2 mu of grassland resources, and the grass is processed from corn stalks and pasture planted during idle seasons. The manure from beef cattle is composted to make organic fertilizer, which is used to replace traditional chemical fertilizers in planting Chinese medicinal herbs, fruits, vegetables, and other crops.

Improved large-scale standardized breeding: Based on large-scale standardized breeding, feed refinement, adding probiotics and enzyme preparations, and other methods are used to reduce feed input and the emission of pollutants and methane during breeding. The improved method can reduce 20% of feed input, 20% of water pollutant emissions, and 50% of methane emissions[10].

Medium-scale breeding: Farmers combine farming with a family breeding farm of about 50 heads, feeding beef cattle with agricultural and forestry residues and purchased commercial feed. The manure produced by beef cattle is sold to an organic fertilizer company to make organic fertilizer, which is used to replace traditional chemical fertilizers in planting Chinese medicinal herbs, fruits, vegetables, and other crops.

Improved medium-scale breeding: Based on medium-scale farming, feed refinement, adding probiotics and enzyme preparations, and other methods are used to reduce feed input and the emission of pollutants and methane during breeding. The improved method can reduce 20% of feed

[10] Zhang, X., Wang, R., Ma, Z., et al. Enteric methane emissions and mitigation strategies in ruminants. Journal of Agro-environmet science, 2020, 39(4): 732-742.

input, 20% of water pollutant emissions, and 40% of methane emissions[11].

Small-scale breeding: Farmers combine farming with small-scale livestock breeding of less than 10 heads, feeding beef cattle with agricultural and forestry residues, planted feed, and finely ground grassland pasture. The manure produced by beef cattle is simply composted and used as organic fertilizer for the farm, achieving the recycling of nutrients such as nitrogen and phosphorus.

[11] The material input, pollutant emissions, and methane emissions of the improved medium-scale livestock farming are assumed to be based on the improved large-scale standardized farming, which assumes that the levels of material input and pollutant emissions are the same as the latter, and methane emissions are slightly lower than the latter.

Table 4.2 Input and emission characteristics of different beef cattle breeding methods

Input	**Unit**	Eco-ranch	Large-scale std.	Improved large std.	Medium-scale	Improved medium-scale	Small-scale
Crude feed *	t/head/year	7.30	9.13	7.30	14.60	11.68	14.60
Refined feed*	t/head/year	1.95	1.28	1.02	0.55	0.44	0.55
Running water*	t/head/year	9.10	12.78	12.78	10.95	10.95	10.95
Electricity*	kwh/head/year	1.20	276.50	276.50	313.00	313.00	0.00
Antibiotics*	mg/head/year	100.00	100.00	100.00	100.00	100.00	100.00
Vaccines*	mg/head/year	100.00	100.00	100.00	100.00	100.00	100.00
Emissions	**Unit**	Eco-ranch	Large-scale std.	Improved large std.	Medium-scale	Improved medium-scale	Small-scale
COD-water**	kg/ head/year	96.34	96.34	77.07	972.02	777.62	1388.60
Total N-water**	kg/ head/year	3.16	3.16	2.53	36.05	28.84	51.50
N-ammonia-water**	kg head/year	0.22	0.22	0.18	0.98	0.78	1.40
Total P-water**	kg/ head/year	0.54	0.54	0.43	6.23	4.98	8.90
CH_4-burp***	kg/ head/year	35.30	35.30	17.65	47.80	28.68	47.80
CH_4-fart***	kg/ head/year	0.90	0.90	0.45	1.20	0.72	1.20

Std.: standardized breeding; TN: total nitrogen;

* Data from field surveys

** Data built upon assumptions in previous sections and values in the Handbook of Agricultural Pollution Source Production and Discharge Factors of Yunnan Province

*** You, 2008; Xue et al., 2014 and assumptions made in earlier sections

4.2.2 Conventional plantation

Conventional crops: cultivation of staple grains (maize and paddy rice) and oilseed crops (oilseed rape).

Endemic species: the cultivation of endemic varieties of significant genetic and cultural values. The main variety in Tengchong is Xi-hong-ruan rice.

Intercropping: refers to the model that plants different kinds of crops on the same land according to a specific spacing rule. It is a production model that uses planting space and resources to increase crop yield per unit of land area and reduce fertilizer use. In Tengchong, the main inter-cropping species sets include tobacco-soybean, corn-soybean, and oil-seed rape-soybean, and the current planting area is about 10% of the total arable land. We assume a 30% reduction in resource input and emissions while maintaining yield compared to traditional cropping methods[12]。

Crops hold different input and output characteristic under different scenarios. Table 4.3 showcases the relevant characteristics of maize cultivation.

[12] See Jensen et al., 2020 in Bibliography.

Table 4.3 Maize input and output characteristics

	Category	Unit	2020	BAU-2025	BAU-2035	BAU-2050	Optimistic-2025	Optimistic-2035	Optimistic-2050
Input*	Seed	kg	1.03	1.03	1.03	1.03	1.03	1.03	1.03
	Pesticide	ml	56.92	53.75	46.22	46.22	46.22	41.71	38.23
	Plastic mulch	kg	1.03	1.03	1.03	1.03	1.03	1.03	1.03
	Irrigation-water	t	1.25	1.25	1.25	1.25	1.25	1.25	1.25
	Irrigation-electricity	kwh	1.00	1.00	1.00	1.00	1.00	1.00	1.00
	Urea	kg	25.07	23.35	20.23	20.23	20.23	18.40	15.49
	Phosphorus pentoxide	kg	11.91	11.09	9.61	9.61	9.61	8.74	7.36
	Potassium oxide	kg	11.75	10.94	9.48	9.48	9.48	8.62	7.26
	Farmyard manure	kg	66.35	156.93	321.11	321.11	321.11	417.35	570.21
	Arable diesel	L	1.60	1.60	1.60	1.60	1.60	1.60	1.60
	Machinery transport	km	1.28	1.28	1.28	1.28	1.28	1.28	1.28
Main output*	Maize	kg	800.00	800.00	800.00	800.00	800.00	800.00	800.00
	Maize straw	kg	1015.23	1015.23	1015.23	1015.23	1015.23	1015.23	1015.23
Atmospheric emissions**	Farmyard manure N_2O	g	0.79	1.86	3.81	3.81	3.81	4.96	6.77
	Farmyard manure NH_3	g	8.76	20.71	42.39	42.39	42.39	55.09	75.27
	Farmyard manure NO	g	1.62	3.83	7.84	7.84	7.84	10.19	13.92
	Fertilizer NO_X	g	0.08	0.19	0.38	0.38	0.38	0.50	0.68
	Fertilizer N_2O	g	188.37	175.43	151.99	151.99	151.99	138.25	116.42
	Fertilizer NH_3	g	618.93	576.43	499.39	499.39	499.39	454.24	382.51
	Fertilizer NO	g	56.16	52.30	45.31	45.31	45.31	41.22	34.71
	Fertilizer NO_X	g	18.72	17.43	15.10	15.10	15.10	13.74	11.57
	Pesticide atmospheric	g	0.03	0.03	0.02	0.02	0.02	0.02	0.02
Water emissions**	Farmhouse manure nitrates	g	45.36	107.30	219.56	219.56	219.56	285.37	389.89

Farmhouse manure phosphate	g	5.20	12.30	25.17	25.17	25.17	32.72	44.70
Fertiliser nitrate	g	2694.51	2509.48	2174.11	2174.11	2174.11	1977.52	1665.28
Fertiliser phosphate	g	10.40	9.69	8.39	8.39	8.39	7.63	6.43

* Data from field surveys;

** Data from field surveys and studies of the convergence coefficients of different fertilisers and pesticides: see bibliography: Brentrup et al., 2004; Cai et al., 1985; Cao et al., 2004; Dijkman et al., 2017；Guo et al., 2016; Huang et al., 2006; Quan et al., 2017; Tian et al., 2001; Yu and Zhu, 2015; Zheng et al., 2000；Zhu et al., 2019.

4.2.3 Under-canopy plantation

Under-canopy plantation: In primary or secondary forest ecosystems with a certain degree of stability, the rich organic matter and soil resources of the forest understory are used to produce agricultural products, mainly medicinal herbs, edible mushrooms, and other high-value-added crops that require better growth environment, without affecting the function and stability of the forest ecosystem itself.

4.3 The BAU policy scenario

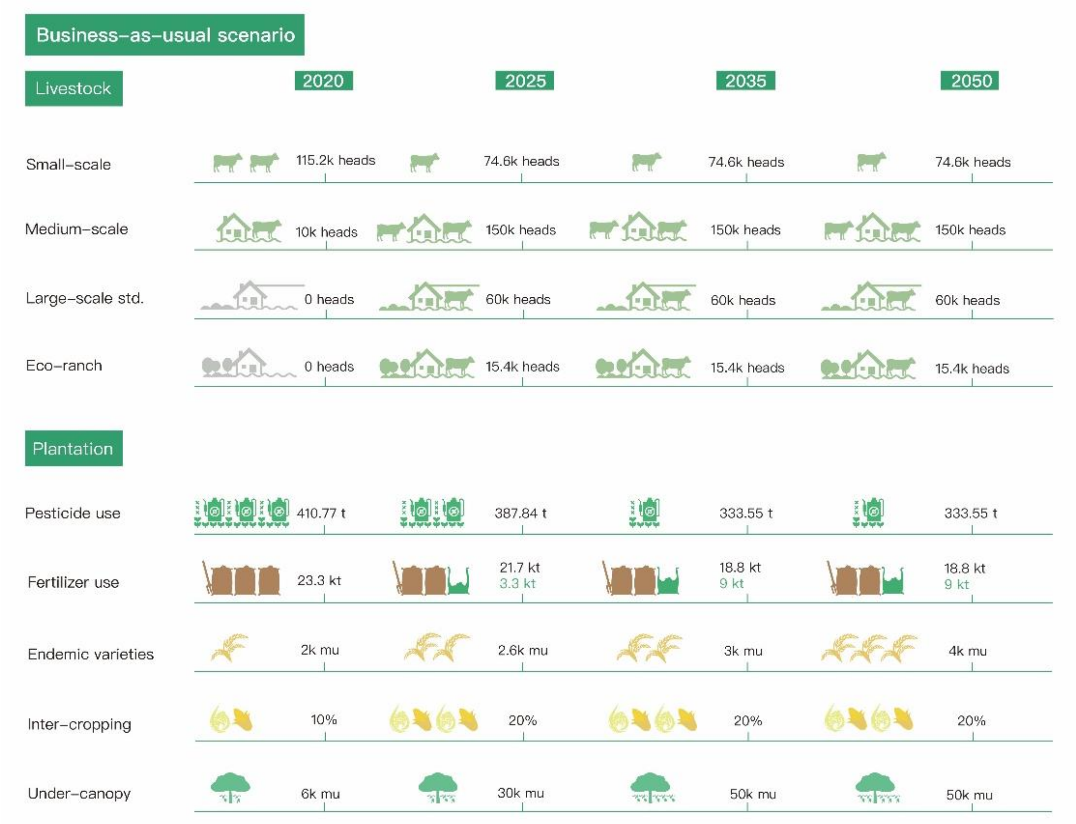

Figure 4.1 Graphic description of business-as-usual (BAU) scenario

Under a fixed increase in the total number of cattle, the beef cattle sector will promote the development of large-scale breeding, medium-scale breeding, and eco-ranch models, and gradually reduce the "small-scale breeding" model. The plantation sector will reduce the use of pesticides and fertilizers, and develop the cultivation of endemic species, intercropping, and under-canopy plantation.

Total beef cattle breeding grows from 125,200 heads in 2020 (of which approx. 10,000 heads under the medium-scale breeding model, the rest in the small-scale breeding model) to 300,000 heads in 2025 and remains unchanged in 2035 and 2050. In 2021, beef cattle farming mainly consisted of a combination of medium-scale (10,000 head) and small-scale (115,200 head) breeding. The changes in the scale of different breeding modes by 2025, 2035, and 2050 are as follows:

- Eco-ranches: By 2025, there will be an additional 20,000 mu of eco-ranches and 15,400 beef cattle, and the development of eco-tourism. The scale will remain unchanged in 2035 and 2050.

- Large-scale standardized breeding: By 2025, there will be 200 new standardized breeding farms and 60,000 beef cattle. The numbers will remain the same in 2035 and 2050.

- Medium-scale farming: By 2025, the number of cattle raised through medium-scale farming will reach 150,000 (among 3,000 households), and this number will remain the same in 2035 and 2050.

- Small-scale breeding: By 2025, the number of cattle bred through small-scale breeding will decrease to 74,600. This number will remain unchanged in 2035 and 2050.

Conventional crops: Pesticide use decreases from 410.77 tons to 387.84 t[13] in 2025 and to 333.55 t[14] in 2035, and maintains zero growth until 2050. Chemical fertilizer use decreases from 23,300 t in 2020 to 21,700 t[15] in 2025 (with an increase of 3,300 tons of organic and farmyard fertilizer[16]), to 18,800 t[17] by 2035 (with an increase of 9,000 tons of organic and farmyard fertilizers), and remain unchanged in 2050.

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).

Intercropping: the percentage of arable land for mix-cropping grows from 10% in 2020 to 15% in 2025 and remains unchanged in 2035 and 2050.

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.

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13 According to the "14th Five-Year Plan for Agricultural Green Development", the national utilization rate of pesticides in 2020 was 40.6%, and it is expected to increase to 43% in 2025. Therefore, the expected utilization of pesticides in Tengchong in 2025 is 387.84 tons, calculated as 410.77 * 40.6% / 43%.

14 Assuming that the utilization rate of pesticides in 2035 increases to 50% (taking into account that the current utilization rate in Europe and the United States is 60%). See: Yi, X., Yuan, M., Yi, C. The chemicals input status and transformation path of the planting industry in China. Strategic Study of CAE, 2017, 19(4):124-129。

15 According to the "14th Five-Year Plan for Agricultural Green Development", the utilization rate of fertilizers in China was 40.3% in 2020, and is expected to increase to 43% by 2025. Therefore, the expected utilization of fertilizers in Tengchong in 2025 would be 2.33*40.3%/43% = 2.18 million tons.

16 Assuming that the use of farmyard manure and organic fertilizers increases in proportion to the reduction of chemical fertilizers, and that the nitrogen element in chemical fertilizers is replaced by an equal amount of nitrogen element in organic fertilizers (farmyard manure) for calculation purposes.

17 Assuming that the utilization rate of pesticides in 2035 increases to 50% (taking into account that the current utilization rate in Europe and the United States is 60%). See: Yi, X., Yuan, M., Yi, C. The chemicals input status and transformation path of the planting industry in China. Strategic Study of CAE, 2017, 19(4):124-129。

4.4 The optimistic policy scenario

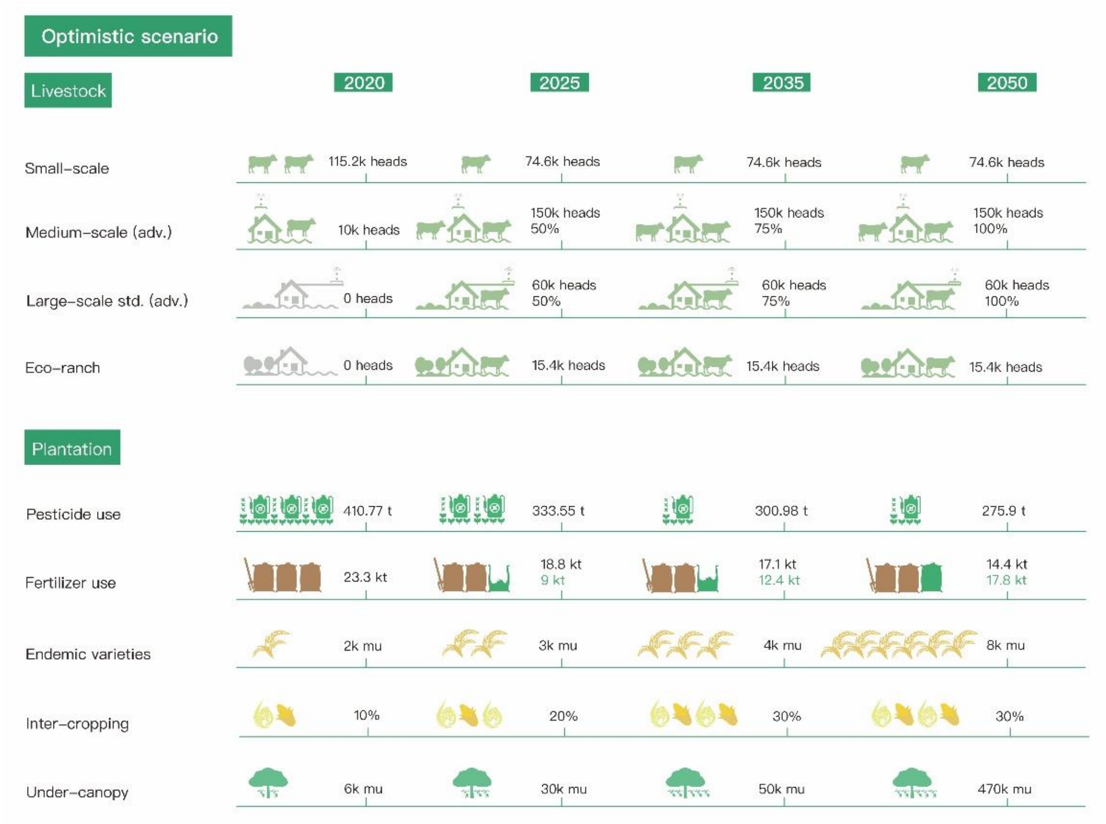

Figure 4.2 Graphic description of optimistic scenario

On the basis of the BAU scenario, improved breeding methods are gradually being developed under the "large scale standardised" and "medium scale breeding" models; the plantation industry is further reducing the use of chemical fertilisers and pesticides, increasing the proportion of endemic species planted and intercropping, and increasing the scale of under-canopy plantations.

- Eco-ranches: by 2025, 20,000 mu (appr. 1333 ha) of new eco-ranches and 15,400 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.

- Large-scale 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. Among them, 50% of the large-scale standardized farms in 2025 will adopt improved methods and control their methane emissions by means such as feed refinement and the addition of probiotics and enzymes in the feed. The proportion of adopting the climate-friendly breeding methods will rise to 75% in 2035, and to 100% in 2050.

- Medium-scale breeding: by 2025, 2,800 new family farms will be present, reaching 3,000 family farms in total, which results in the total number of medium-scale breeding increased from 10,000 heads in 2020 to 150,000 heads in 2025. The number will remain unchanged in 2035 and 2050. Among them, 50% of the family farms will adopt improved methods and control their methane emissions in 2025 by means such as feed refinement and the addition of probiotics and enzymes. The proportion of adopting the climate-friendly breeding methods will rise to 75% in 2035, and to 100% in 2050.

- Small-scale breeding: by 2025, the cattle raised under the small-scale breeding model reduced to 74,600 heads; the number will remain unchanged in 2035 and 2050.

Conventional crops: Pesticide use decreases from 410.77 tons to 333.55 t[18] in 2025 and to 300.98 t[19] in 2035, and to 275.90 t[20] in 2050. Chemical fertilizer use decreases from 23,300 tons in 2020 to 18,800 t[21] in 2025 (with an increase of 9,000 tons of organic and farmyard fertilizers), to 17,100 t[22] in 2035 (with an increase of 12,400 organic and farmyard fertilizers), and to 14,400 t[23] (with an increase of 17,800 tons of organic and farmyard fertilizers) in 2050.

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).

Intercropping: by 2025, the percentage of arable land for mix-cropping grows to 20%, to 30% by 2035, and remains unchanged in 2035 and 2050.

Under-canopy plantation: area under plantation will increase from 6,000 mu (2019; 400 ha) to approximately 30,000 mu (2025; 2000 ha), to approximately 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).

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[18] Referring to the current pesticide use rate of 55-60% in Europe and the US, it is assumed that the use rate of pesticides in Tengchong will reach 50% in 2025, that is 410.77×40.6%/50%=333.55 tons. See Yi., et al. 2017.

[19] Referring to the current pesticide use rate of 55-60% in Europe and the US, it is assumed that the use rate of pesticides in Tengchong will reach 55% in 2025, that is 410.77×40.6%/55%=303.22 tons.

[20] Referring to the current pesticide use rate of 55-60% in Europe and the US, it is assumed that the use rate of pesticides in Tengchong will reach 60% in 2025, that is 410.77×40.6%/60%=277.95 tons.

[21] The current use rate of nitrogen in fertilizers is 65% in Europe. Referring to this number, we assume the use rate of chemical fertilizers in Tengchong will be 50% in 2035, that is 23,300×40.3%/50%=18,800 tones.

[22] The current use rate of nitrogen in fertilizers is 65% in Europe. Referring to this number, we assume the use rate of chemical fertilizers in Tengchong will be 55% in 2035, that is 23,300×40.3%/55%=17,100 tones.

[23] The current use rate of nitrogen in fertilizers is 65% in Europe. Referring to this number, we assume the use rate of chemical fertilizers in Tengchong will be 60% in 2035, that is 23,300×40.3%/60%=14,400 tones.

4.5 The pessimistic policy scenario

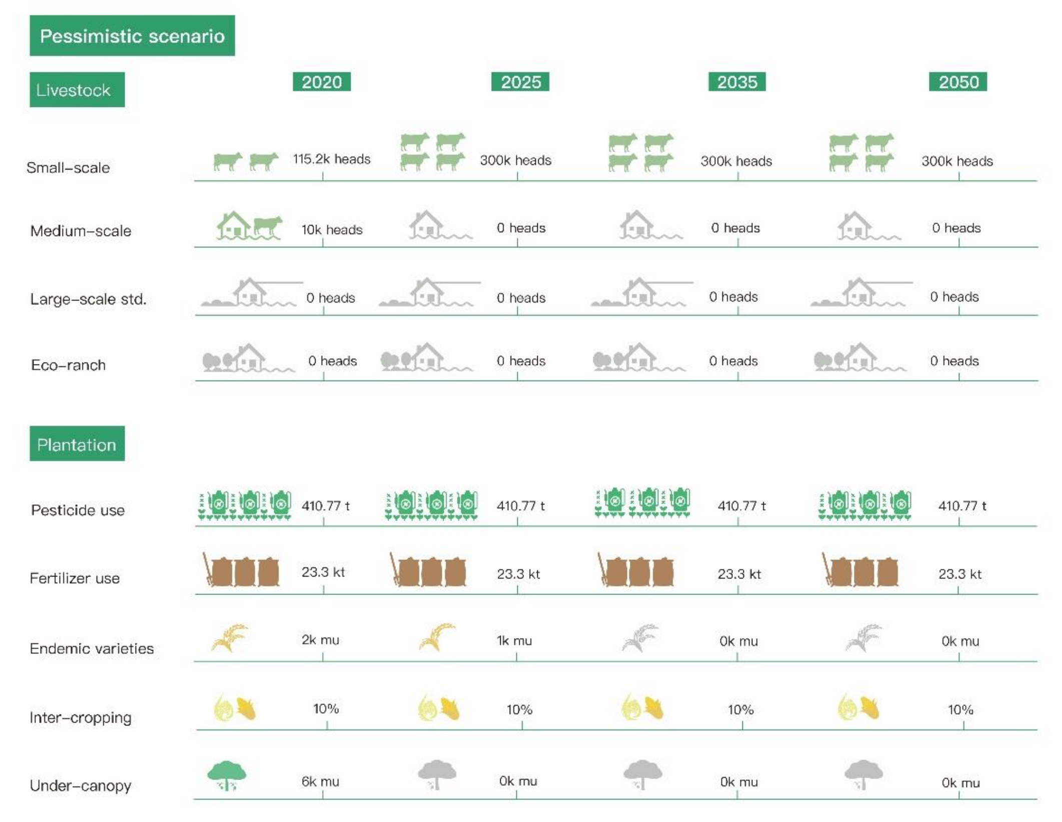

Figure 4.3 Graphic description of pessimistic scenario

In 2025, 2035 and 2050, beef cattle breeding will be developed in a single "small-scale breeding" model; the use of chemical fertilisers and pesticides in the plantation industry will maintain at the 2020 level, the area planted with endemic species will gradually reduce, the proportion of intercropping will be maintained at the 2020 level, and no under-canopy plantations will be developed.

- Eco-ranches: no development of eco-ranches.
- Large-scale standardized breeding: no development of large-scale standardized breeding.
- Medium-scale breeding: no development of medium-scale breeding.
- Small-scale breeding: By 2025, 300,000 beef cattle head will all be raised in small-scale breeding mode, and remain unchanged in 2035 and 2050.

Conventional crops: the total amount of pesticide use will remain at the current level of 410.77 tons (2020) in 2025, 2035, and 2050. The use of chemical fertilizers will remain at 23,300 tonnes in 2025, 2035, and 2050, with zero increase in organic fertilizers and farmyard manure use.

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.

Intercropping: the percentage of arable land for mix-cropping will remain at the current level of 10% (2020) in 2035, 2035 and 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.

5. Analysis framework and methodology

This study refers to the TEEBAgriFood evaluation framework and analyzes the costs and benefits generated by the development scenarios from the perspective of four types of capital: natural capital, produced capital, human capital, and social capital. Table 5.1 shows the content of the four types of capital included in the analysis.

In terms of natural capital benefits, the analysis includes ecosystem regulating services such as water provision, water purification, soil retention, pollination, and carbon sequestration (with the exception of pollination services, which were not valued), as well as recreational enabling services. The cost analysis covers emissions of air, water, and solid pollutants, as well as greenhouse gas emissions. The accounting methods and formulas for calculating each type of ecosystem service are detailed in Table 5.2 and Annex 1.

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

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" (Healy and Cote, 2001), including health, education, job skills, traditional knowledge, etc. This study analyzes the benefits in terms of labor quantity and skills training, as well as the health costs associated with occupational exposure, air pollution exposure, downstream water body exposure, and agricultural product consumption exposure. Labor quantity is represented by the number of participating laborers. Information on labor skill training (type, frequency, duration, and level) was obtained through surveys. The accounting methods and formulas for calculating health costs are detailed in Table 5.2 and Annex 1.

Social capital includes "the networks, norms, values, and understandings that facilitate cooperation within and between groups" (OECD, 2007). 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 (UNU-IHDP and UNEP, 2014), etc. This study qualitatively analyzes the benefits of social capital from the perspectives of female 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 of the agricultural cooperatives in Tengchong County are estimated based on the number of cooperatives engaged in under-canopy and the assumption that cooperatives can increase the net sales unit price by 5% (data source: stakeholder interviews).

Table 5.2 shows the research topics that have been quantitatively assessed and the methods used, including physical quantity assessment methods and value quantity assessment methods. The calculation formulas for the relevant methods are detailed in Annex 1.

Table 5.1 Categories assessed in the project

Capital	Benefit	Cost
Natural	Ecosystem services: recreation enabling, water provisioning, water purification, soil retention, pollination, carbon sequestration	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[24]
Produced	Crop and livestock production	Input of agricultural materials (energy, fuel, fertilizers, pesticides, etc.)
Human	Quantity of labour, skills training	Health impacts: occupational exposure, exposure to air pollution, exposure to downstream water bodies, and exposure to consumption of agricultural products.
Social	Female empowerment, social mechanisms (agricultural cooperatives)	/

[24] The greenhouse gases in this report include carbon dioxide, methane, nitrous oxide, and all other greenhouse gases included in the IPCC's fifth report.

Table 5.2 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 behavior 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, belowground biomass, soil, and dead organic matter) under different land uses.	The economic value of carbon sequestration service is calculated according to the standard of 28.6 yuan per 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)[25].
	Recreation enabling	/	The consumer expenditure method calculates the

[25] 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

			cost of reaching a recreational site, such as fuel, transportation fees, tolls, etc., but does not include food costs.
Natural Capital - Pollution and Greenhouse Gas Emissions Costs	Water pollutants (Livestock farming: Chemical Oxygen Demand, Total Nitrogen, Ammonia Nitrogen, Total Phosphorus; Agriculture: Nitrate, Phosphate, Pesticides)	The material quantity of water pollutants is calculated using the coefficient method. The emission coefficients for livestock farming are taken from the "Agricultural Source Production and Pollution Accounting Method and Coefficient Handbook" published by the Ministry of Ecology and Environment of the People's Republic of China in 2021, while those for agriculture 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 "Yunnan Province Environmental Protection Tax Collection and Levying Standards," to quantify the environmental costs of pollutants.
	Air pollutants (Livestock farming: Methane; Agriculture: Ammonia Nitrogen, Nitrous Oxide, Nitric Oxide, Nitrogen Dioxide, Methane, Pesticides)	Based on emission factors reported in the literature for different types of agriculture and livestock farming, 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 for livestock farming mainly come from the "Accounting Methods and Coefficient Handbook for Agricultural Sources of Pollutants" published by the Ministry of Ecology and Environment of the People's Republic of China in 2021, while those for agriculture 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 "Yunnan 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 gases is calculated based on a standard of 40 US dollars/ton of carbon dioxide equivalent).
	Solid Waste (Unused Straw, Abandoned Animal Manure)	The quantity of unused straw and abandoned animal manure was investigated using a questionnaire survey. As no unused straw or abandoned animal manure was found during the survey, no analysis was conducted in the report.	/
	Life Cycle Greenhouse Gas Emissions (Carbon dioxide,	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

	methane, and nitrous oxide).		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 dioxide equivalent.
Produced capital – crop benefits	Crops (rice, corn, wheat, rapeseed) and livestock products (beef and milk)	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	Calculating the chemical's lifetime theoretical maximum contribution (LTMCs) [26] and converting it into a human health damage factor (CF) [27], and using Disability Adjusted Life Years (DALYs) [28] to represent health (life) loss.	The calculation is done by multiplying the Disability-Adjusted Life Years (DALYs) by the Value of Statistical Life (VSL)[29].

[26] 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.

[27] 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).

[28] 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.

[29] 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.

	agricultural production).		
	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 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 fertilizers used in agricultural production.	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 integrated in SimaPro software, and the health risk characterization factor (CF) is represented by disability-adjusted life years (DALYs).	The statistical value of a life (VSL) is multiplied by DALYs to calculate the economic value of health losses.
	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.

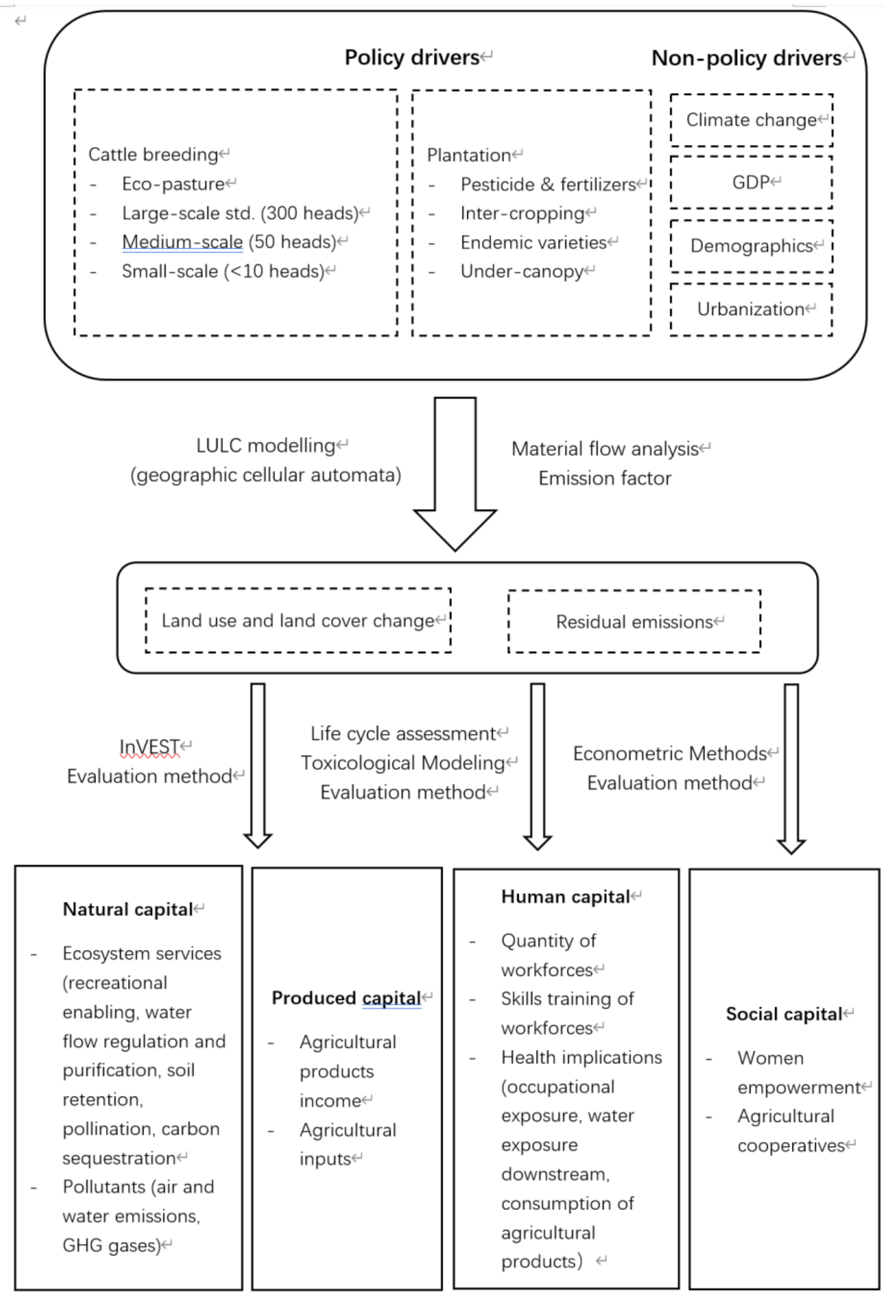

Figure 5.1 Analysis flow chart

6. Land-cover and land-change modelling

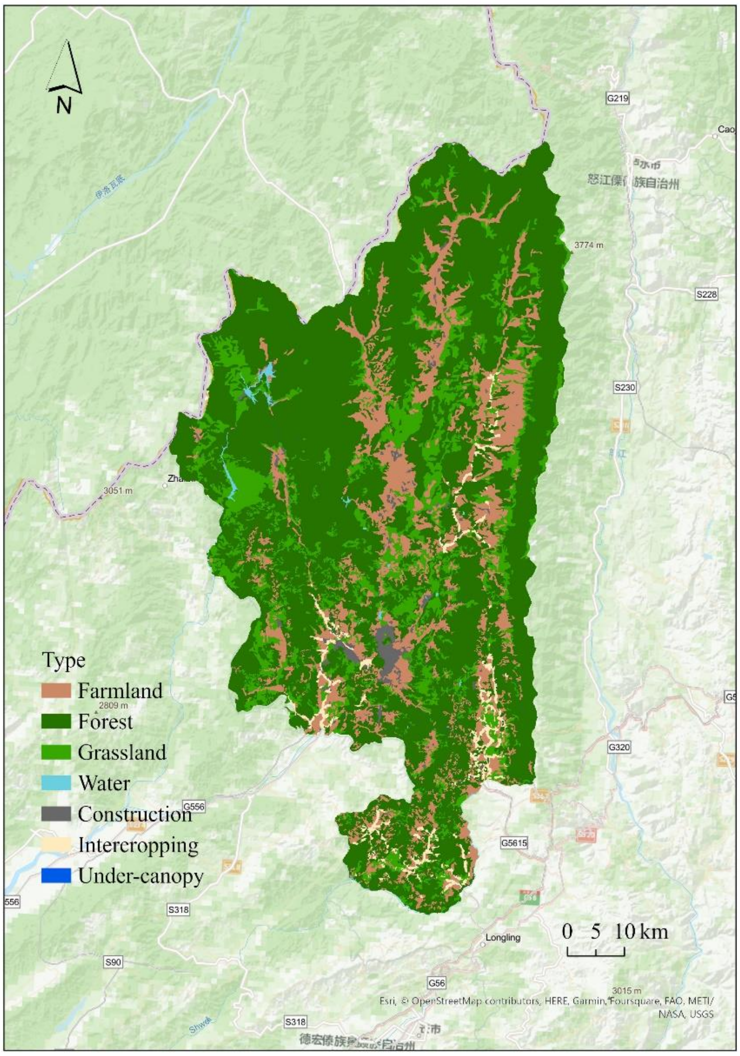

Figure 6.1 Land-use conditions in Tengchong City in 2020

This study takes the land use and cover status of Tengchong City in 2020 (Figure 6.1) as the starting point, and simulates future land use types by overlaying social and economic drivers and natural forces, based on the change trends from 2000 to 2020. The overall results show that there will not be significant changes in land use and cover in Tengchong City at three time points in the short, medium, and long terms (2025, 2035, and 2050) (Table 6.1). This is mainly due to China's strict land use policies that protect land resources such as farmland, forestland, and grassland. Between the RCP4.5 and RCP8.5 climate scenarios, only the area of water bodies shows significant differences, while other land use types show little variation between the scenarios.

Table 6.1 Main land use types in Tengchong

Time	Climate scenario	Policy pathway	Plantation area	Forest	Under-canopy	Grassland	Ranches	Waterbody	Construction land
2020	/	/	1559672	5493969	5588	1275098	0	26850	118596
2025	RCP4.5	BAU	1553161 (-0.4%)	5488441 (-0.1%)	28101 (402.9%)	1278611 (0.3%)	18596	40580 (51.1%)	113393 (-4.4%)
2025	RCP 4.5	Pessimistic	1554659 (-0.3%)	5494035 (0%)	0 (-100%)	1278832 (0.3%)	0	32787 (22.1%)	113872 (-4%)
2025	RCP 4.5	Optimistic	1559684 (0%)	5509775 (0.3%)	28090 (402.7%)	1277344 (0.2%)	18578	26383 (-1.7%)	100999 (-14.8%)
2025	RCP 8.5	BAU	1554081 (-0.4%)	5487989 (-0.1%)	28096 (402.8%)	1278979 (0.3%)	18621	40766 (51.8%)	112370 (-5.2%)
2025	RCP 8.5	Pessimistic	1555613 (-0.3%)	5494593 (0%)	0 (-100%)	1279194 (0.3%)	0	31296 (16.6%)	113490 (-4.3%)
2025	RCP 8.5	Optimistic	1561222 (0.1%)	5509345 (0.3%)	28079 (402.5%)	1277712 (0.2%)	18579	26224 (-2.3%)	99683 (-15.9%)
2035	RCP 4.5	BAU	1566846 (0.5%)	5495864 (0%)	46727 (736.2%)	1283646 (0.7%)	18583	26440 (-1.5%)	101390 (-14.5%)
2035	RCP 4.5	Pessimistic	1534539 (-1.6%)	5496783 (0.1%)	0 (-100%)	1253192 (-1.7%)	0	50489 (88%)	138159 (16.5%)
2035	RCP 4.5	Optimistic	1551716 (-0.5%)	5484813 (-0.2%)	46679 (735.3%)	1245481 (-2.3%)	18618	53912 (100.8%)	137240 (15.7%)
2035	RCP 8.5	BAU	1566843 (0.5%)	5495850 (0%)	46727 (736.2%)	1283663 (0.7%)	18583	26440 (-1.5%)	101390 (-14.5%)
2035	RCP 8.5	Pessimistic	1534410 (-1.6%)	5496789 (0.1%)	0 (-100%)	1249074 (-2%)	0	54657 (103.6%)	138232 (16.6%)
2035	RCP 8.5	Optimistic	1551851 (-0.5%)	5484656 (-0.2%)	46693 (735.6%)	1245230 (-2.3%)	18588	54180 (101.8%)	137244 (15.7%)
2050	RCP 4.5	BAU	1566942 (0.5%)	5494307 (0%)	46719 (736.1%)	1285108 (0.8%)	18583	26440 (-1.5%)	101390 (-14.5%)
2050	RCP 4.5	Pessimistic	1564598 (0.3%)	5495082 (0%)	0 (-100%)	1286000 (0.9%)	0	26574 (-1%)	101932 (-14.1%)
2050	RCP 4.5	Optimistic	1568480 (0.6%)	5503244 (0.2%)	466883 (8255.1%)	1276213 (0.1%)	18583	25995 (-3.2%)	100254 (-15.5%)
2050	RCP 8.5	BAU	1566946 (0.5%)	5494324 (0%)	46723 (736.1%)	1285086 (0.8%)	18583	26440 (-1.5%)	101390 (-14.5%)
2050	RCP 8.5	Pessimistic	1564595 (0.3%)	5495082 (0%)	0 (-100%)	1286002 (0.9%)	0	26574 (-1%)	101932 (-14.1%)
2050	RCP 8.5	Optimistic	1568519 (0.6%)	5503257 (0.2%)	466865 (8254.8%)	1276162 (0.1%)	18583	25995 (-3.2%)	100254 (-15.5%)

Unite of change is *mu* (667 m^2); percentage calculated using the 2020 value as reference.

From the perspective of arable land, the total area has changed slightly, but there have been changes in the use of arable land, with some traditional planting patterns being converted to intercropping. It is expected that by 2025, in the BAU scenario, the area of traditional planting will decrease by 6%, in the pessimistic scenario, it will decrease by less than 1%, but in the optimistic scenario, it will decrease by about 11%, mainly due to the rapid development of intercropping in the agricultural system under the optimistic scenario. Correspondingly, in the optimistic scenario of 2025, the area of intercropping has increased nearly twofold, increased by about 50% in the BAU scenario, and remained relatively unchanged in the pessimistic scenario. By 2035, the area of traditional planting will basically remain the same as in 2025 under the BAU and pessimistic scenarios, but will further decrease by 13% in the optimistic scenario compared to 2025. In contrast, the area of intercropping will further increase by 49% in the optimistic scenario of 2035 compared to 2025. By 2050, the area of traditional planting will basically remain the same as in 2035, and so will the area of intercropping.

The total area of forest land in Tengchong City will not undergo significant changes, but under-canopy plantation will be carried out. In 2025 under all scenarios, the other forest land in Tengchong City (forest land that has not developed understory crop patterns, including natural forests and economic forests, etc.) will basically remain the same as in 2020. The expansion of under-canopy plantation area accounts for less than 0.5% of the total forest land area in Tengchong City. By 2035, the area of under-canopy plantation will still remain the same as in 2025 under the BAU and pessimistic scenarios, and will expand by about 70% in the optimistic scenario. By 2050, the area of under-canopy plantation will basically remain the same as in 2035 under the BAU and pessimistic scenarios, while further expanding to about 470,000 acres, about ten times that of 2035, under the optimistic scenario.

Similar to forest land, the total area of grassland in Tengchong City will not undergo significant changes, but some grasslands will develop into eco-ranches. The development pattern is relatively stable, with about 1% of the grassland area converted to eco-ranches in the BAU and optimistic scenarios of 2025, while the total area of grassland remains basically unchanged in the pessimistic scenario, and this state will continue until 2050.

7. Analysis of natural capital

7.1 Pattern of change

As the starting point of the analysis, Table 7.1 shows the material and value quantities of various ecosystem services in Tengchong City in 2020. Among them, the value of water conservation and soil conservation is the highest, at 8.952 billion yuan and 14.637 billion yuan, respectively. The value of water purification function (N and P) is 950,000 yuan and 670,000 yuan, respectively. The value of carbon storage is 3.93 billion yuan.

The simulation results for future scenarios show that the quantities of these four types of ecosystem regulating services - water conservation, water purification, soil conservation, and carbon fixation - are relatively high, with differences between climate pathways but not sensitive to policy pathways (Figure 7.1). Tengchong City has a good natural background and is under long-term protection of national policies, such as the National Soil and Water Conservation Plan (2015-2030), the protection plan for water conservation areas at all levels of government, and the natural forest resource protection program, which ensures the stable supply of these four types of regulating services, which are essential for maintaining the output of other types of ecosystem services and the development of economic and social activities. The impact of different agricultural policy pathways on these four types of services is relatively small, indicating that the Tengchong ecosystem has strong resilience and can resist external disturbances.

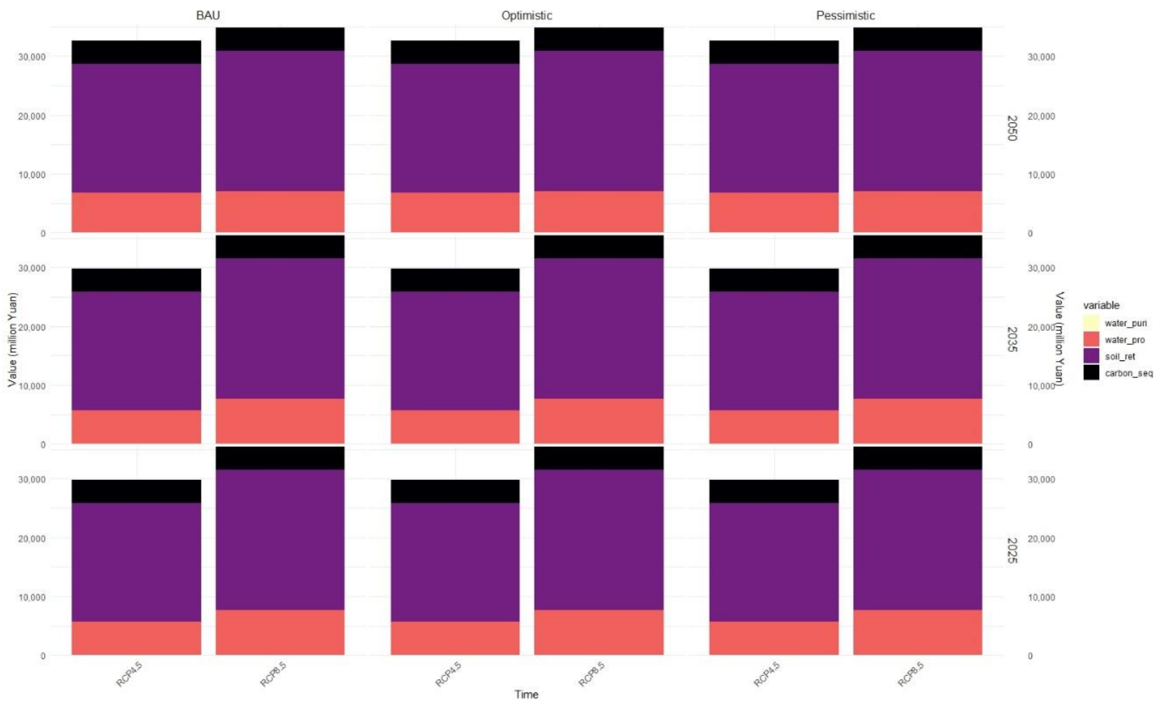

Figure7.1 Values of the water provisioning, water purification, soil retention and carbon sequestration services

The supply of recreational enabling services, as well as the emissions of pollutants and greenhouse gases, although within the scope of natural capital accounting, have much smaller quantities compared to the four regulating services mentioned above and are more susceptible to the impact of agricultural policy pathways. Overall, the positive scenario has a significant advantage in pollutant and greenhouse gas emissions. For example, in 2050 (Table 7.1), the cost of pollutant emissions in the positive scenario is 26.62% lower than that in the baseline scenario, mainly due to the fine management of cattle breeding in the positive scenario, which reduces the emissions of pollutants such as COD, total nitrogen, and total phosphorus into water bodies. In terms of greenhouse gas emissions, the positive scenario is 9.98% lower than the baseline scenario, also due to measures such as fine feed management, adding probiotics and enzyme preparations, etc. to reduce methane emissions during cattle breeding in the positive scenario. Although the positive scenario has increased methane emissions in the planting industry through measures such as extensive use of organic fertilizers, overall, greenhouse gas emissions in the positive scenario are still lower. In terms of leisure support services, the positive scenario is about three times that of the baseline scenario, mainly due to the significant benefits brought by the development of eco-tourism under forest cover.

Considering that the differences in quantity values between different climate scenarios (RCP4.5 and RCP8.5) mainly reflect on the four regulating services of water conservation, water purification, soil conservation, and carbon fixation, and they are not significantly affected by the agricultural development pathway under the current strict ecological environment protection system, they are not the constraining factors for the future development of Tengchong City. The quantities of other types of accounting results are relatively small, and the differences between different climate scenarios are also small. Therefore, the following chapters will mainly choose the results of one type of climate scenario (RCP4.5) for explanation and analysis.

Table 7.1 Natural capital patterns in Tengchong City

Time	Policy path	Climate scenario	Natural Capital (million Yuan)								
			Benefit						Cost		Benefit-cost
			Water pro.	Soil ret.	Water pur.	Carbon seq.	Recreation ena.	Pollination[a]	Pollutant emissions	GHG	Net value
2020	/		8951.57	14637.18	-1.62	3929.6	3.04	0.423	-250.21	-28.6	27240.96
2025	BAU	RCP4.5	5677.35	20205.52	-1.77	3930.44	139.76	0.422	-451.7	-54.62	29444.98
2025	Pessimistic	RCP4.5	5683.06	20203.01	-1.8	3940.42	0	0.38	-607.2	-57	29160.49
2025	Optimistic	RCP4.5	5674.6	20205.47	-1.74	3929.69	139.63	0.378	-353.31	-52.22	29542.12
2035	BAU	RCP4.5	5676.82	20199.97	-1.75	3926.46	271.74	0.38	-451.34	-56.63	29565.27
2035	Pessimistic	RCP4.5	5695.39	20209.34	-1.88	3929.69	0	0.377	-607.15	-56.91	29168.48
2035	Optimistic	RCP4.5	5701.58	20209.32	-1.91	3930.09	272.08	0.377	-341.87	-50.55	29718.74
2050	BAU	RCP4.5	6814.15	21858.96	-2.02	3933.47	642.07	0.38	-451.34	-56.64	32738.65
2050	Pessimistic	RCP4.5	6814.15	21859.97	-2.02	3919.27	0	0.382	-607.23	-57.04	31927.1
2050	Optimistic	RCP4.5	6813.39	21854.98	-2.02	3926.1	1919.05	0.379	-331.18	-50.99	34129.33
2025	BAU	RCP8.5	7614.34	23850.78	-1.98	3926.46	139.91	0.378	-451.6	-53.29	35024.62
2025	Pessimistic	RCP8.5	7622.63	23850.81	-2.01	3929.69	0	0.378	-607.21	-57.01	34736.9
2025	Optimistic	RCP8.5	7623.81	23850.61	-2.01	3930.09	139.63	0.379	-353.33	-54.14	35134.66
2035	BAU	RCP8.5	7618.23	23850.06	-1.96	3937.24	271.74	0.38	-451.35	-58.54	35165.42
2035	Pessimistic	RCP8.5	7626.69	23863.54	-2.1	3928.16	0	0.377	-607.15	-56.91	34752.23
2035	Optimistic	RCP8.5	7620.37	23860.36	-2.08	3927.78	271.76	0.377	-341.96	-54.39	35281.84
2050	BAU	RCP8.5	7107.92	23850.86	-1.88	3936.53	642.08	0.38	-451.35	-58.55	35025.61
2050	Pessimistic	RCP8.5	7107.92	23849.65	-1.89	3934.84	0	0.38	-607.23	-57.04	34226.25
2050	Optimistic	RCP8.5	7108.45	23851.06	-1.88	3934.47	1919	0.379	-331.42	-58.17	36421.51

The calculation for water conservation is based on the product of the quantity of water and the water price of 3.45 yuan/m^3 (according to the Yunnan Statistical Yearbook 2020). The calculation for soil conservation is based on the product of the quantity of soil, the soil capacity parameter, and the fertilizer price (N fertilizer price of 1776.85 yuan/t, P fertilizer price of 2351.25 yuan/t; soil capacity parameter: N element 0.10%, P element 0.04%). The calculation for water purification is based on the product of the quantity of N/P in wastewater and the cost of treating N/P in wastewater (N wastewater treatment cost of 1500 yuan/t, P wastewater treatment cost of 2500 yuan/t35). The calculation for carbon sequestration is based on the product of the quantity of carbon and the carbon price (the CO2-eq price in the carbon trading market in 2020 was 28.6 yuan/t, according to http://www.chinacarbon.info/).

[a] The value of the pollen amount (a) is dimensionless and relative, and therefore has no corresponding value.

7.2 Key emissions and local absorption capacity

7.2.1 Carbon source and carbon sink

As shown in the previous section, Tengchong has a good natural background, with a large forest coverage area, and the natural ecosystem provides a large amount of carbon sequestration function. For example, in 2020, the ecosystem carbon fixation capacity of Tengchong was 37.4718 million tons of carbon dioxide equivalent. Compared with natural carbon sinks, the greenhouse gas emissions from Tengchong's agricultural system are relatively small. In 2020, the greenhouse gas emissions from Tengchong's agricultural system throughout its lifecycle were 999,800 tons of carbon dioxide equivalent, accounting for about 2.67% of its carbon sequestration capacity for the year.

Figure 7.2 shows the comparison between the lifecycle carbon footprint of Tengchong's agricultural system and natural carbon sinks in future years. In the future, the greenhouse gas emissions from Tengchong's agricultural system throughout its lifecycle will increase, and its proportion to carbon sequestration will increase from 2.67% in 2020 to around 5%. By 2050, the proportions of greenhouse gas emissions to carbon sequestration under baseline, positive, and negative scenarios will be 5.29%, 4.75%, and 5.32%, respectively. Overall, the increase in agricultural emissions brought about by the development of Tengchong's agricultural system will not affect its "net carbon sink" attribute, and under the positive scenario, greenhouse gas emissions will have the smallest proportion to carbon sequestration.

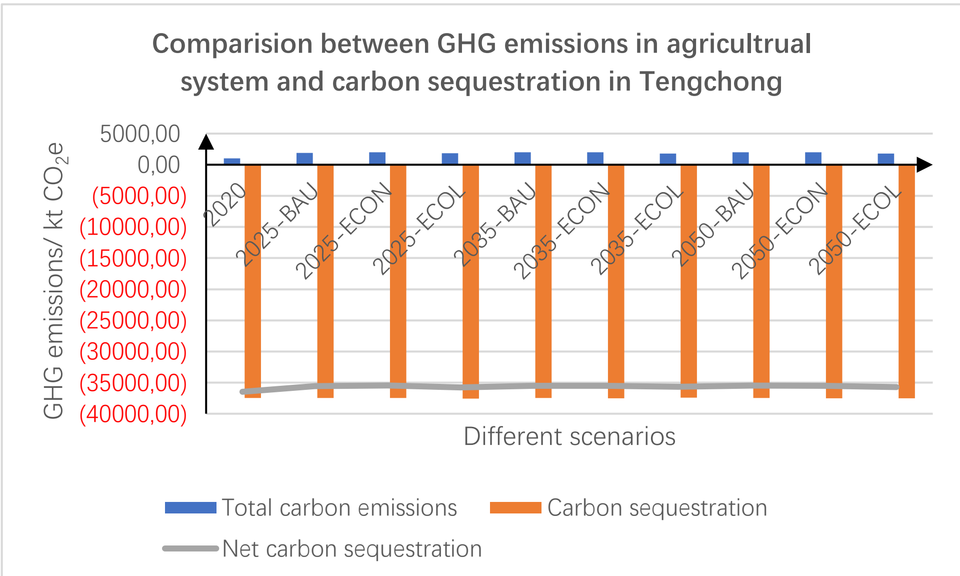

Figure 7.2 Full life-cycle carbon footprint of Tengchong's agricultural systems compared to its annual carbon sequestration

7.2.2 Water pollutant emissions and water purification capacity

The comparison between the discharge of water pollutants (total nitrogen and total phosphorus) from the Tengchong agricultural-food system and the water purification capacity of the natural ecosystem is shown in Figure7.3. For total nitrogen, the proportion of nitrogen absorbed by the water purification function of the natural ecosystem is less than 7% of the total nitrogen emissions, with the highest value being 6.96% in the optimistic scenario in 2050. For total phosphorus, the proportion of phosphorus absorbed by the water purification function of the natural ecosystem is also less than 25% of the total phosphorus emissions, with the highest value being 23.28% in the optimistic scenario in 2020.

It can be seen that the water pollution caused by the agricultural-food system far exceeds the natural ecosystem's purification capacity. Among them, beef cattle farming contributes the most to the pollution of total nitrogen and total phosphorus, and fertilizer leaching from planting and understory planting is also an important source of nitrogen and phosphorus pollution. Therefore, in the transformation of the Tengchong agricultural-food system, the management of wastewater and feces from beef cattle farming should be strengthened, and various measures should be taken to treat nitrogen and phosphorus pollution to the water system. At the same time, precision fertilization should be adopted to reduce the leaching of nutrients and thus reduce nitrogen and phosphorus pollution in water.

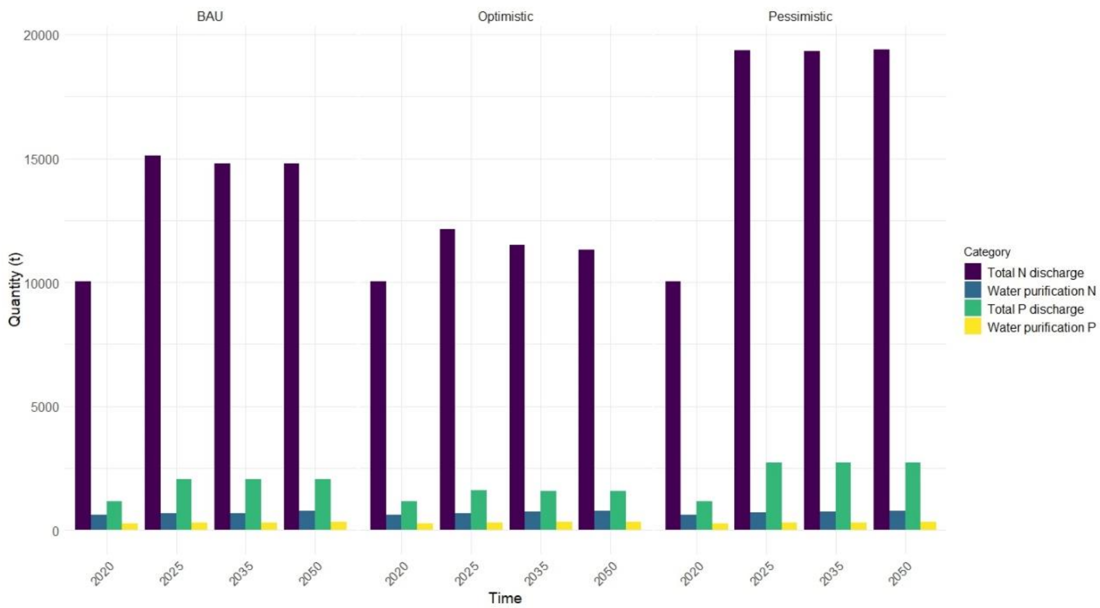

Figure 7.3 Total nitrogen (N) and total phosphorus (P) water pollutant emissions compared with the water quality purification capacity of the natural ecosystem.

8. Analysis of produced capital

By comparing the produced capital (Table 8.1), we see that the advantage of the optimistic scenario mainly lies in the output and income of crops. Taking the year 2050 as an example, the crop output and income of the optimistic scenario is 18.98% higher than that of the BAU scenario, thanks to the widespread promotion of undergrowth planting, which produces high-value agricultural products such as traditional herbal medicines. However, there is little difference in the income of livestock products among the three scenarios, and in the optimistic scenario, due to the adoption of new technologies and management measures such as precision management, enzyme preparations, and probiotic additives in animal husbandry, the operating costs have increased, thereby reducing the net value of livestock product output. Taking 2050 as an example, this investment resulted in a 13.35% lower net value of livestock products in the optimistic scenario compared to the BAU scenario.

Table 8.1 Comparison of produced capital

Produced capital (million Yuan)					
		Benefit		Cost	Benefit - cost
Time	**Policy path**	**Crop**	**Livestock**	**Input cost**	**Net**
2020	/	1720.56	1430.79	1751.49	1399.86
2025	BAU	2570.54	3469.21	3244.30	2795.45
2025	Pessimistic	2421.37	3430.64	3236.80	2615.21
2025	Optimistic	2606.04	3469.21	3303.39	2771.86
2035	BAU	3837.71	3451.74	3230.82	4058.63
2035	Pessimistic	3607.98	3424.84	3231.58	3801.24
2035	Optimistic	3956.99	3451.74	3353.20	4055.53
2050	BAU	6968.27	3425.55	3244.78	7149.04
2050	Pessimistic	6791.60	3416.14	3239.62	6968.12
2050	Optimistic	8291.54	3425.55	3397.60	8319.49

Note: Showing 2020-eq. monetary value; due to the insignificant differences between the results of RCP4.5 and RCP8.5, only the results under RCP4.5 climate scenario are presented and analysed.

Although quantifying implicit values is important, at this stage, practitioners in agriculture (farmers or businesses) still base their decisions on visible costs and benefits. Comparison of net profit of agricultural products (only considering cultivation input and agricultural product revenue) in Tengchong shows that transitioning to an optimistic path will generate a very small amount of benefit for the farmers (less than 5 Yuan/mu). Although the positive returns are small, they are not negative (as is sometimes claimed), so that it should not be a constraint on making the switch.

9. Analysis of human capital

Table 9.1 Comparison of human capital values

Human capital						
		Labour quantity (person)		Benefit (million Yuan)	Cost (million Yuan)	Benefit – cost (million Yuan)
Time	**Policy path**	**Male**	**Female**	**Labour income**	**Health cost**	**Net**
2020	/	15226	19341	823.45	99.35	724.1
2025	BAU	16287	20428	982.56	96.47	886.09
2025	Pessimistic	15367	19348	928.66	100.21	828.45
2025	Optimistic	16061	20072	967.32	85.47	881.85
2035	BAU	16639	20854	1221.85	85.61	1136.24
2035	Pessimistic	15157	19086	1115.37	100.11	1015.26
2035	Optimistic	15636	19377	1142.50	77.50	1065
2050	BAU	16653	20868	1550.65	85.64	1465.01
2050	Pessimistic	15450	19458	1441.74	100.21	1341.53

2050	Optimistic	20713	25390	1910.75	70.37	1840.38

Note: Showing 2020-eq. monetary value; due to the insignificant differences between the results of RCP4.5 and RCP8.5, only the results under RCP4.5 climate scenario are presented and analysed.

Table 9.1 shows the quantified values of human capital calculated based on measurable data, including labour income (benefits) and health impacts (costs). It can be seen that the optimistic scenario has certain advantages in labour income and health impacts, and the advantages are more pronounced in the long term. For example, in 2050, labour income in the optimistic scenario is 23.22% higher than that in the BAU scenario (with a total value of 25.62% higher), thanks to the promotion of under-canopy plantation that has created a large number of job opportunities, especially for female laborers. Similarly, in 2050, the health impacts in the optimistic scenario are 17.83% lower than those in the BAU scenario, thanks to the measures taken to reduce the use of pesticides and increase efficiency in the planting process.

In addition to labour income, this study also qualitatively analysed labour quantity and labour skill training. Labour quantity will increase under the optimistic scenario, mainly due to the beef cattle breeding and under-canopy industries. As all beef cattle breeding in the pessimistic scenario is developed in a small-scale mode, there is less demand for labour. In the optimistic scenario, however, the under-canopy model is expected to expand vigorously, and by 2050, when it reaches about 470,000 mu, more labour is needed for professional planting, cultivation, harvesting, and other work. Therefore, the optimistic scenario will have more employed people (total of 46,103 people) in 2050, especially female laborers (as shown in Table 9.1). In comparison, the BAU scenario can provide a total of 37,251 jobs in 2050, while the pessimistic scenario can only provide 34,908 jobs.

Labour skill training mainly involves technicians and management personnel in the scaled breeding, eco-ranch, and under-canopy industries, but it does not involve the temporary workforce (which accounts for a large proportion of the labour force). In terms of the proportion of training personnel, technicians account for about 8%, 11%, and 51% of the total employment in the scaled breeding, eco-ranch, and under-canopy industries, respectively, while management personnel account for 2%, 1%, and 15%, respectively. Under the future scenario, as the scale and labour force of these three industries change, the number of people who receive skill training will also change accordingly. It is estimated that by 2025 and 2035, the number of laborers who receive skill training in the BAU and optimistic scenarios will not differ much, but by 2050, the development of the under-canopy model in the optimistic scenario will increase the total number of trained laborers. In the pessimistic scenario, however, the scaled breeding, eco-ranch, and under-canopy models are not developed, resulting in very few laborers receiving skill training.

10. Analysis of social capital

This study analyses the development of social capital from the perspectives of the social mechanisms brought about by agricultural cooperatives and women's empowerment. The analysis of the social mechanisms of agricultural cooperatives is based on data obtained from surveys of different types of cooperatives and focuses on the under-canopy plantation industry, which has a better-promoted cooperative model. Women's empowerment is analysed through the employment of female labour in under-canopy plantation and ecological pasture.

There are four under-canopy plantation cooperatives in Tengchong City in 2020, involving 68 households and a total planting area of 1626 mu, accounting for 30.92% of the total developed under-canopy plantation area (Table 10.1). It is estimated that under-canopy plantation agricultural cooperatives in Tengchong City can bring about an additional income of about 5% for under-canopy agricultural products by increasing product prices and providing stable sales channels.

Table 10.1 Added-value brough forth by the cooperative production mode

					Benefit (million Yuan)
Time	Policy path	No. of cooperatives	Participating households	Percentage of under-canopy occupied	Added-value[a]
2020	/	4	68	30.92% (1626mu)	0.41
2025	BAU	24	408	48.60% (13655mu)	318
2025	Pessimistic	0	0	0	0
2025	Optimistic	24	408	48.60% (13655mu)	318
2035	BAU	48	816	81.82% (38233mu)	903
2035	Pessimistic	0	0	0	0
2035	Optimistic	52	884	88.73% (41419mu)	979
2050	BAU	48	816	81.82% (38233mu)	903
2050	Pessimistic	0	0	0	0
2050	Optimistic	388	6596	100% (485,000mu)	1100

[a]: Refers to the added-value brought by the agricultural cooperative production model for crop production. Only results under the RCP4.5 climate scenario are shown. Showing 2020-eq. monetary value.

Based on the current situation of the cooperatives, a future scenario analysis is conducted (Table 10.1). By 2025, under the BAU and optimistic scenarios, the number of under-canopy plantation cooperatives will develop to about 24, with an average area of 569 mu, accounting for 48.6% of the developed under-canopy area, and will bring about an additional income of approximately 3.18 million yuan to forestry plantation farmers. By 2035, there is a slight difference between the BAU and optimistic scenarios. Under the BAU scenario (48 cooperatives, average area of 797 mu, accounting for 82% of the developed under-canopy area), an additional income of approximately 9.03 million yuan can be generated, while under the optimistic scenario (52 cooperatives, average area of 797 mu, accounting for 89% of the developed under-canopy area), an additional income of approximately 9.79 million yuan can be generated. By 2050, there will be no further changes in the BAU scenario, but under the optimistic scenario, the cooperative model will continue to expand (388 cooperatives, average area expanded to 1,250 mu, covering all available under-canopy land resources), which will drive approximately 6,596 farmers to engage in planting operations and bring them approximately 11 million yuan in additional income.

Currently, the Tengchong agricultural system mainly achieves women's economic empowerment by providing employment opportunities. Although women do not have an advantage in technical and management positions, more female temporary workers are employed in the production process of ecological pastures and under-canopy plantation industries. For example, about 80% of the employees in ecological pastures are temporary workers (mainly engaged in grass planting and harvesting), of which more than 90% are women. About half of the employees in under-canopy plantation are temporary workers (mainly engaged in fertilization, weeding, harvesting, etc.), of which about 70% are women. Therefore, the future development of ecological pastures and under-canopy plantation industries, especially under-canopy industries, will provide more sources of income for women, which is particularly significant in the optimistic scenario.

11. Analysis of the four capitals

Table 11.1 shows the overall situation of Tengchong's agri-food system in natural capital, produced capital, human capital, and social capital. The results indicate that the total net value (benefit minus cost) of the four types of capital in all future scenarios is higher than the baseline net value in 2020, and the differences increase with time. The total net value of the four capitals in Tengchong in 2020 is 29.368 billion yuan, equivalent to 1.04 times the city's GDP (28.235 billion yuan) that year. By 2025, the total net value will increase to 1.15-1.18 times the 2020 GDP, while in 2035, it will be 1.20-1.23 times, and in 2050, it will be 1.43-1.57 times.

At all three time points in the future, the total net value of the four capitals in the optimistic scenario is higher than that in the BAU, while the total net value in the pessimistic scenario is lower than that in the BAU, but the differences are not significant. For example, in 2050, the total net value in the optimistic scenario is 2.937 billion yuan (7.10%) higher than that in the BAU, while the total net value in the pessimistic scenario is 1.116 billion yuan (2.70%) lower than that in the BAU.

Table 11.1 Summary comparison of the four capitals

Time	Policy path	Natural capital							Produced capital			Human capital		Social capital	
		Benefit					Cost		Benefit		Cost	Benefit	Cost	Benefit	
		Water prov.	Soil rete.	Water puri.	Carbon sequ.	Recreation enab.	Pollutants	GHG	Crops	Livestock	Input	Labour income	Health cost	Added-value[a]	Net
2020	/	8951.57	14637.18	1.62	3929.60	3.04	250.21	28.60	1720.56	1430.79	1751.49	823.45	99.35	0.41	29368.57
2025	BAU	5677.35	20205.52	1.77	3930.44	139.76	451.70	54.62	2570.54	3469.21	3244.30	982.56	96.47	318	33448.06
2025	Pessimistic	5683.06	20203.01	1.80	3940.42	0.00	607.20	57.00	2421.37	3430.64	3236.80	928.66	100.21	0	32607.75
2025	Optimistic	5674.60	20205.47	1.74	3929.69	139.63	353.31	52.22	2606.04	3469.21	3303.39	967.32	85.47	318	33517.3
2035	BAU	5676.82	20199.97	1.75	3926.46	271.74	451.34	56.63	3837.71	3451.74	3230.82	1221.85	85.61	903	35666.65
2035	Pessimistic	5695.39	20209.34	1.88	3929.69	0.00	607.15	56.91	3607.98	3424.84	3231.58	1115.37	100.11	0	33988.74
2035	Optimistic	5701.58	20209.32	1.91	3930.09	272.08	341.87	50.55	3956.99	3451.74	3353.20	1142.50	77.50	979	35822.09
2050	BAU	6814.15	21858.96	2.02	3933.47	642.07	451.34	56.64	6968.27	3425.55	3244.78	1550.65	85.64	903	42259.74
2050	Pessimistic	6814.15	21859.97	2.02	3919.27	0.00	607.23	57.04	6791.60	3416.14	3239.62	1441.74	100.21	0	40240.79
2050	Optimistic	6813.39	21854.98	2.02	3926.10	1919.05	331.18	50.99	8291.54	3425.55	3397.60	1910.75	70.37	1100	45393.24

[a]: Refers to the added-value brought by the agricultural cooperative production mode.

Only results under the RCP4.5 climate scenario are shown. Showing 2020-eq. monetary value.

Based on the total value of water conservation services, water purification services, soil conservation services, and carbon sequestration services in Tengchong City (as shown in Table 7.1), which far exceed the total value of other natural capital benefits and costs, and as these four services are fundamental ecosystem regulating services that are influenced by long-term national conservation policies, they are less sensitive to Tengchong's agricultural transformation measures. In contrast, all other accounting contents, including produced capital, human capital, and social capital, as well as recreational enabling, pollutant emissions, and greenhouse gas emissions in natural capital, are closely linked to the agricultural development mode, and are therefore more sensitive to agricultural transformation. In order to more clearly demonstrate the impact of agricultural transformation, further analysis will exclude the values of water conservation, water purification, soil conservation, and carbon sequestration services.

The total net value of the **accounting categories more susceptible to agricultural transformation** (including all produced, human and social capital, as well as leisure support, pollutant emissions, and greenhouse gas emissions in natural capital) are shown in Figure 11.1. There are significant differences in the value between the scenarios, and the differences in the medium and long term are more significant than those in the short term. By 2050, compared with the baseline scenario, the total net value increased by 33.71% in the positive scenario, while it decreased by 12.61% in the negative scenario. The main differences come from human capital (reduced health impacts and increased labor income), natural capital (reduced pollutant emissions and improved leisure support), and produced capital (increased agricultural product output).

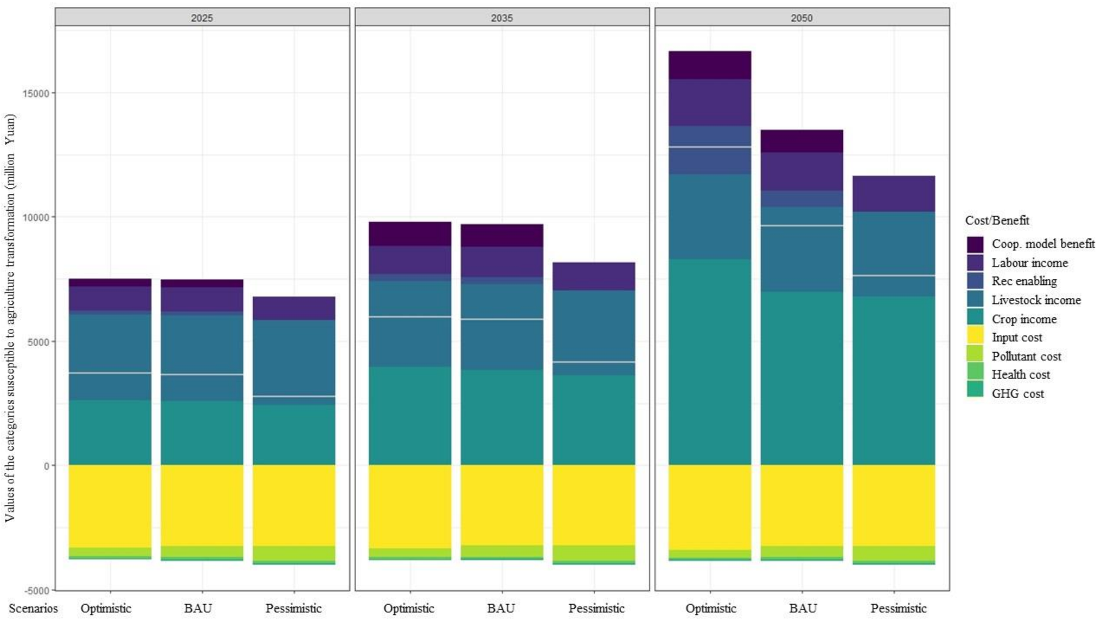

Figure 11.1 Comparison of capitals more susceptible to agricultural transformation in Tengchong City (including all produced, human and social capital, as well as leisure support, pollutant emissions, and greenhouse gas emissions in natural capital). Grey horizontal lines denote total net values.

Sensitivity analysis using carbon price variation

Tengchong has a good forest coverage and environmental conditions, and its agricultural and food system's greenhouse gas emissions are relatively small compared to natural carbon sinks, and will remain so in the foreseeable future (2.67% of total carbon sink in 2020, and a maximum of 5.32% in 2050). Therefore, carbon emitted by the agricultural and food system will not remain in the atmosphere for a long time, which means the social cost of carbon (SCC) in Tengchong is almost zero. However, to ensure the results are robust and rigorous, we still use SCC for sensitivity analysis.

We used the national average SCC (10.9 USD per ton of carbon dioxide equivalent, equivalent to RMB 78 per ton of carbon dioxide equivalent[30]) for sensitivity analysis calculations. After replacing the market carbon price (28.6 yuan per ton of carbon dioxide equivalent, equivalent to 4 USD per ton of carbon dioxide equivalent), the total value of services increased in different scenarios, with an absolute increase ranging from 66.93 to 67.38 billion RMB and a growth rate ranging from 15.11% to 22.94%, but the inter-scenario patterns remain the same. Taking the optimistic scenario in 2050 as an example, the total value increased from 442.93 billion RMB to 509.87 billion RMB. With reference to Tengchong's GDP in 2020 (282.35 billion RMB), this represents an increase from 156.88% to 180.58%.

12. Policy implications

In recent years, China's sustained attention to the harmonious development of humans and nature and the protection of the ecosystems and the environment at the national level has led to strict protection of important ecosystem function and service supply areas. These policies will continue to be implemented in the foreseeable future, laying the foundation for the Green to Gold transformation. The transformation of the agricultural food system needs to strengthen the provision of other services while protecting these natural foundations and balancing the comprehensive improvement of natural, produced, human, and social capitals.

By applying the TEEBAgriFood evaluation framework in the Tengchong context, several policy recommendations are proposed based on the study results. These recommendations are organized around related policy priorities or flagship programs, and target at different levels from local to national. In this section, we will introduce four main recommendations with considerations on the enabling conditions for the implementation of them, and then discuss a policy mainstreaming strategy based on China’s decision-making regime. At the end of this section, the relationship with the Kunming-Montreal Global Biodiversity Framework is presented.

12.1 Recommendations and enabling conditions

1. Integrating the whole systems thinking and accounting the market-invisible costs and benefits to support sustainable agriculture development and the country’s Green to Gold transformation.

Applying the whole systems thinking in agriculture and food system implies that not only activities and impacts within the productive farms are accounted for, but also their interactions with the supporting ecosystems, as well as the impacts passing through the value chain reaching peoples.

[30] 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

In the Tengchong case, changes in the provision of ecosystems services among the three future scenarios (business as usual, optimistic, and pessimistic) are simulated and monetized. Such analysis provides useful information to decision makers in local development planning. For example, the quantitative values of the ecosystem regulating services in Tengchong are high, and they are insensitive to different agricultural development paths as set in the study. This, on the one hand, acknowledges the achievements of the long-term protection of natural ecosystems by national and local policies (as witnessed by the forest cover maintained at 75% for a long time), and on the other hand, suggests that Tengchong has good natural capital as the basis for local agricultural development. Other data such as the comparison of the level of pollutant discharge to the water purification capacity and differences in human health implications over time and among scenarios are useful information for public policymaking as these issues have a “common land” feature, are ignored by the market regulation and should be taken care for by the public sector.

Although we know that the enormous ecosystem service value is a great wealth, changes on the ground rely on the behaviour subjects (businesses, cooperatives, and households) instead of the government. However, these agricultural agents may not be able to directly obtain actual benefits from the “added values” at the macro level (such as environment improvement or public health benefits), and they will not have enough motivation to bear higher transformation costs. In this regard, the whole systems thinking could also offer insights from the individual decision-making perspective as it also pays attention to the economic cost and returns (i.e., produced capital). In the Tengchong context, it is indicated that the adoption of more eco-friendly farming practices does not impose higher operational costs (as indicated by expenditures and revenues), and in the long run, it can be economic-advantageous. Knowing that, government could enable changes from several aspects: 1) strengthen publicity to demonstrate both the economic sustainability and the long-term environmental and health benefits that eco/sustainable agricultural practice can bring; 2) strengthen financial and technical support and encourage farmers to switch to eco-friendly methods through subsidies; 3) help unlocking the potential for people to consume green agricultural products (organic, green, etc.).

As China embedded the term *Ecological Civilization* in its constitutions, the concept of *Green is Gold* is fully embraced by the governments at all levels demonstrated by the issue of various policies and implementation of flagship programs, including the *Opinions on Establishing a Sound Mechanism for Realizing the Value of Ecological Products*, which provides general guidance at the national level for the valuation and transformation of ecosystem services, as well as the establishment of the *Green is Gold* practice innovation bases at local levels making the case of good Green to Gold transformations models. The application of the whole systems thinking in assessing Tengchong’s agricultural transformation guided by the TEEBAgriFood evaluation framework and interdisciplinary methodology demonstrates the merits of this approach in supporting a Green to Gold transformation by informing sustainable agricultural decision-making given the crucial role that agri-food systems play in shaping our relationship with nature. Mr. Runqiu Huang, the Minister of Ecology and Environment of China and the President of the CBD COP15, highlighted the significance of "applying the TEEB method in specific areas and scenarios to make socio-economic activities more friendly to biodiversity", further reinforcing the value of utilizing the TEEBAgriFood approach in supporting the country’s transformation.

2. Agricultural water pollution discharge as a limiting factor for local development should be

controlled by multiple measures.

Water purification function of natural ecosystems is far less that the discharge of water pollutants with the main contributors being livestock farming and planting activities – this holds true in all the three scenarios in the Tengchong study. Water pollution could become a major challenge for local development, and agricultural non-point pollution control is urgent.

Reducing the use of chemical fertilizers and pesticides through improving efficiency is an important policy in China, which has significantly promoted the utilization efficiency of fertilizers and pesticides and led to a reduction in pollutant emissions and improvement in food safety and human health. By 2050, in the optimistic scenario, pollutant emission cost is estimated to be 27% and 45.5% lower than the business-as-usual and pessimistic scenarios, respectively. Similarly, health costs in the optimistic scenario are 17.4% and 29.8% lower than the two scenarios, respectively. But even if the chemical use rate is improved to the level of Europe and the United States, natural ecosystems can only consume less than 7% of total nitrogen discharges and less than 25% of total phosphorus discharges by 2050. This shows that other technical and engineering measures should be combined to improve water pollutant discharge. For planting activities, more emphasis should be placed on accurate fertilization (such as soil testing and formula fertilization) on the basis of reducing input and increasing efficiency to improve fertilizer utilization and reduce the temporary entry of pollutants into the water environment. For livestock farming, it is necessary to establish sewage treatment infrastructure to reduce the discharge of pollutants into the water environment. The substitution of organic fertilizers for chemical fertilizers is an important measure for reducing usage, but attention should also be paid to the increased methane emissions resulting from the use of organic fertilizers, especially in rice cultivation.

Tengchong's agricultural non-point source pollution challenge is not unique. According to the *Bulletin on the Second National Census on Pollution Sources (2020)*[31], the pollutants discharged from agricultural sources have a greater impact on the water environment nationwide, and plantation and livestock farming are the main sources of total nitrogen and total phosphorus in water bodies. Noteworthy, China has always been a country with extremely poor freshwater resources, with per capita possession less than one-third of the world’s average. Water pollution threatens water security and health of people’s life. The Ministry of Agriculture and Rural Affairs, the Ministry of Ecology and Environment and other relevant national ministries and commissions have intensively issued policies strengthening the prevention and treatment of agricultural non-point source pollution in a comprehensive manner, including the *Implementation Opinions on the Battle to Prevent and Control Agricultural Non-point Source Pollution*, the *14th Five-Year Plan for Comprehensive Management of the Water Environment in Key Basins* and the *14th Five-Year Plan for the Green Development of the Nation's Agriculture*. Recommendations derived from the Tengchong analysis will have implications for areas and regions with similar situations in the country.

3. Carefully plan for agricultural emissions management to support the local development agenda and the national dual-carbon strategy.

Tengchong's forest ecosystem is a huge carbon sink, with an estimation of carbon sequestration of 37.5 million tons CO_2e in 2020. In contrast, GHG emissions from agricultural system are small

31 https://www.mee.gov.cn/xxgk2018/xxgk/xxgk01/202006/W020200610353985963290.pdf

– in 2020 the estimated GHG emissions from agriculture is 2.67% of its annual carbon sequestration; by 2050, the proportion is estimated to be around 5% in all the three scenarios. Despite the fact that GHG emissions from agriculture are relatively small compared to the city's overall carbon sequestration capacity, the national "Dual Carbon" Strategy[32], which is proposed from a country-wide perspective, will place greater emphasis on methane emissions and inevitably put stringent control over the overall emissions from the primary industry in the future, with methane being the major type of GHG emission reductions.

In fact, China has gradually strengthened its emphasis on methane emission reduction from agricultural activities. *The 12th Five-Year Plan* issued by the State Council in 2012 explicitly proposed to strengthen the treatment and comprehensive utilization of animal husbandry waste to control the growth of methane and other greenhouse gas emissions. *The 13th Five-Year Plan* for the Control of GHG Emissions further specifies the need to control methane emissions from agriculture. In January 2022, the Ministry of Agriculture and Rural Affairs issued the *Guidance Opinions on Promoting the Construction of Eco-Farms*, which proposed that eco-farms should be the key object to explore low-carbon compensation policies on the reduction of emissions of methane and nitrous oxide from paddy field and other farming land, animal enteric fermentation, and livestock and poultry manure. In June 2022, the Ministry of Agriculture and Rural Development and the National Development Reform Commission jointly issued the *Implementation Plan for Reducing Emissions and Carbon Sequestration in Agriculture and Rural Areas*, deploying key tasks of reducing methane and nitrous oxide emissions from agriculture and including the action of reducing methane emissions from paddy fields as one of the ten major actions.

Therefore, for Tengchong, it is necessary to strengthen the control of GHG emissions especially methane and nitrous oxide emissions (mainly from rice cultivation and beef cattle breeding) in agriculture. For rice cultivation, new rice varieties (such as perennial rice), improved use of organic fertilizers, and control of flooding time can be considered for improvement. For beef cattle breeding, methane and nitrous oxide emissions can be reduced through fine feed management (such as low crude protein feed), the addition of enzyme preparations and the addition of probiotics, anaerobic digestion and composting of manure. Application of these emission reduction measures should be selected in the light of local environment conditions and related costs (such as transportation) etc..

The large amount of initial investment, low short-term return, and high technical risk for implementing these measures usually lead to weak market investment motivation for agricultural GHG emission reduction projects. It is recommended that governments improve the incentive mechanism and risk-sharing management mechanism for agricultural GHG emission reduction practice, as well as provide support on pilot testing and training. The voluntary market for Chinese Certified Emission Reduction (CCER) could also play a catalysing role. *The Administrative Measures for Carbon Emission Trading (Trial)* issued in December 2020 specifies that GHG emission reductions from renewable energy, forestry carbon sequestration, methane utilization projects within China's territory, which are quantitatively verified and registered in the National Greenhouse Gas Voluntary Emission Reduction Trading Registration System, can be used as a supplement to the Chinese Emission Allowance (CEA) and to be introduced into the CCER trading. The current CCER methodologies on methane emission reductions include Methane Emission

[32] Referring to China's goal of peaking its carbon emissions by 2030 and achieving carbon neutrality by 2060.

Reduction by Adjusting Water Supply Management Practices in Rice Cultivation (CMS-017-V01), Methane Recovery from Agricultural Activities in Households/Small Farms (CMS-026-V01), and Methane Recovery from Animal Manure Management Systems (CMS-021-V01). There is great potential for Tengchong to explore funding support from CCER trading market for agricultural methane emission reduction projects.

Although it is estimated that Tengchong's carbon sequestration value is high (taking the year 2020 for example, the value calculated by carbon social cost price is about 10% of its GDP in the same year), there are limited ways for realizing these values. In the CCER trading system, afforestation, reforestation and strengthening forest management are endorsed as credible approaches for developing CCER. Still none of them are ideal for Tengchong to apply for, because, on the one hand, the funding support from CCER trading will be limited. On the other hand, forest management in Tengchong can never be driven by the single goal of carbon sequestration given it is a biodiversity hotspot. Further national level policies and guidelines to clarify how forestry carbon sink can support the national "Dual-Carbon" Strategy is needed.

4. Realizing the potential of ecotourism requires carefully managing the development and conservation nexus and taking a multi-stakeholder approach.

Tengchong has extraordinary tourism resources. The study shows that the development of tourism based on eco-ranching and forestry has huge potential in brining economic benefits and job opportunities, but realizing these potentials requires substantial inputs from both the public and private sectors, such as actively developing tourism infrastructure, improving road network construction of tourism resources, and so on.

According to local stakeholder consultations, developing eco-tourism in agricultural and forest landscapes in Tengchong has been very difficult due to very strict land use restrictions. In China, land use control system identifies "three major categories": agricultural land, construction land and unutilized land, and they cannot be easily shifted from one to another. Land directly used for agricultural production such as forest land, arable land, grassland, etc. are categorised as agricultural land and is not allowed to use for constructions. However, developing eco-tourism will inevitably incur constructions of buildings and other infrastructures (even for limited amount). It has proven to be very difficult to apply for the allocation of construction land within agricultural land.

In fact, Tengchong is not alone. There have been debates around the relationship between conservation and development and sustainable use of natural resources for eco-tourism requires careful management and efforts from all stakeholders including government, business, communities, and ecotourists. In order to achieve better coordination of economic development, people's livelihood, and ecological protection, three suggestions are made. Firstly, policies should consider specific conditions in different regions and plan accordingly to make sure the disturbances from eco-tourism will not exceed the threshold of ecosystems. Secondly, once developed, it is necessary to educate tourists on environmental ethics and minimize the environmental impact of the tourism process. Thirdly, for natural resources that are constrained from tourism or other development, such as Tengchong that provides biodiversity conservation and carbon sequestration services, government at national level should take a holistic view and mobilize financial support safeguarding local development, such as through the fiscal transfer payment system.

12.2 Policy mainstreaming roadmap

Policy mainstreaming is a prominent part of the TEEBAgriFood project's implementation in China, which ensures the study is connected to policy. We categorize all the actions done, in progress, and planned into five "pillars" to show how these activities are structured for enhanced science-policy interface.

Pillar 1. National and subnational level policy engagement

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 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.

As an integral department of the State Council, the Ministry of Ecology and Environment (MEE) is the ministry in charge of environmental protection efforts in the country. One of its roles is to formulate and organize the implementation of ecological and environmental policies, plans, and standards. Chinese Research Academy of Environmental Sciences (CRAES), as a subsidiary body of MEE, will submit relevant recommendations based on the TEEBAgriFood study in China to the Ministry.

National policy priorities that are relevant to the study include 1) the updated National Biodiversity Strategy and Action Plan, 2) Opinions on Establishing and Improving the Mechanism for Realizing the Value of Ecological Products, and 3) Regulations for the Construction and Management of "Green is Gold" Practice Innovation Bases and its technical guidelines for assessment.

Pillar 2. Sub-national level policy engagement

The year 2024 to 2025 is the key period for the formulation of the 15th Five-Year Plan across the country. National, provincial, and local level governments will start drafting the 15th Five-Year Plan (2026-2030) for National Economic and Social Development as well as respective sectoral five-year plans, guided by a state-level document issued by the Political Bureau of the Communist Party of China (CPC) providing suggestions on the strategic direction. Several rounds of consultations will be held before the Plan is finally endorsed. Recommendations from the study will be presented to the municipal government of Tengchong to support the drafting of the relevant 15th Five-Year Plans.

Training programs are used to mainstream the value of nature, the systems thinking, and the study recommendations to relevant government officials, for example, through the Tengchong training course for young and middle-aged officials (November 2021).

Pillar 3. Key stakeholder engagement

The project has been implemented in a consultive manner, with the Project Steering Committee (Box 1) providing overall guidance on the direction of the project. A policy mapping was conducted and candidate topics and geographic focuses for the TEEBAgriFood assessment were proposed at the inception workshop (August 2019). Tengchong, a national Green is Gold practice innovation base, was selected as the pilot for the TEEBAgriFood assessment at the first Project Steering Committee (PSC) meeting in July 2020. Since then, stakeholder consultations (October 2020, May 2021, October 2022) and PSC meetings (Feb 2021, May 2022, April 2023) have been held sequentially. The final synthesis report of the TEEBAgriFood Tengchong assessment will be released at the final high-level event of the project in October 2023. The PSC has also been actively engaged with project activities at the international level, such as the speech made by Dr. Junsheng Li at the TEEBAgriFood global symposium in June 2022.

Box 1. Structure of the Project Steering Committee (PSC)

PSC chair:

- Mr. Ning Liu, Deputy Director General, Department of Nature and Ecology Conservation, Ministry of Ecology and Environment of China

PSC members:

- Mr. Yan Zhuang, Director of International Organization Programs, Bureau of International Cooperation, Chinese Academy of Sciences
- Mr. Quanhui Wang, Lead Expert in Energy & Ecology, Rural Energy and Environment Agency, Ministry of Agriculture and Rural Affairs
- Mr. Junsheng Li, Professor, Natural Resources Survey Center, Ministry of Natural Resources of China
- Ms. Linxiu Zhang, Director of International Ecosystem Management Partnership, United Nations Environment Programme
- Mr. Feng Xia, Director of Natural Ecology Protection Division, Department of Ecology and Environment of Yunnan Province
- Mr. Youzhi Yang, Director of Baoshan Ecology and Environment Bureau
- Mr. Yingkao Zhou, Director of Tengchong Branch of Baoshan Ecology and Environment Bureau

Pillar 4. Other dissemination events

The project has been taken advantage of the opportunity that the CBD COP15 being hosted by China as well as many other sub-national, national, and international events to disseminate the key messages and findings derived from the TEEBAgriFood assessment. They are an important means of infusing the recommendations to a wider range of audiences including decision-makers. The key ones include:

- CBD COP15 side event “Recognizing and managing the value of nature’s contribution to people through food systems transformation” (December 2022, Montreal)
- CBD COP15 Ecological Civilization Forum: Lucid Waters and Lush Mountains are Invaluable Assets: from Concept to Practice (October 2021, Kunming)
- Eco Forum Global Guiyang 2023 (July 2023, Guiyang)
- "Science and Innovation in Food System Transformation", Xiangshan Science Conference (August 2022, Beijing)
- Seminar and training session on mechanisms for realizing the value of ecological products in China's biosphere reserves (June 2021)
- Yunnan Think-tank Forum: presentation on Biodiversity Mainstreaming in Yunnan Province (November 2021)

- The 5th CRAES International Master Lecture "Focus synergies of climate adaptation, ecosystem management and sustainable livelihoods for sustainable development" (March 2022)
- Tengchong 2021 training course for young and middle-aged officials (November 2021, Tengchong)
- Agrifood systems in the bioeconomy, IAMO Forum 2021 (June 2021)
- China Agricultural Economics Society 2021 Symposium (October 2021)
- 10th Asian Society of Agricultural Economists (ASAE) International Conference (December 2021)
- COMSTECH Forum on Environment and Ecosystem Restoration and the COMSTECH International Seminar on Land Degradation (June 2022)

Pillar 5. Contributions to the implementation of the Kunming-Montreal Global Biodiversity Framework

The Kunming-Montreal Global Biodiversity Framework (GBF) adopted during the fifteenth meeting of the Conference of the Parties (COP15) to the Convention on Biodiversity Diversity in December 2022 sets out an ambitious pathway to reach the global vision of a world living in harmony with nature by 2050. Among the Framework's key elements are 4 goals for 2050 and 23 targets for 2030. The scope of the TEEBAgriFood project in China through the lens of the Tengchong study fits well in the scope of the Framework and can support its implementation in China in multiple dimensions and though multiple ways. In turn, the Framework could also provide insights for realizing these suggestions.

First of all, the TEEB approach serves as an example of the CBD's long-term strategic approach to policy mainstreaming and how to incorporate natural capitals thinking into the Kunming-Montreal Global Biodiversity Framework. The application of the TEEB approach will help to understand the benefits and losses to nature, people and society from relevant decisions at all levels (policies, goals and targets, strategies and action plans), and encourage the evaluation of natural's contribution to people and the introduction of economic mechanisms to promote the internalization of externalities (e.g. payment for ecosystem services). The TEEBAgriFood framework for assessment focuses particularly on the major driver of biodiversity loss and aims to re-orient the undesirable agricultural activities that have exacerbated biodiversity loss and ecosystems degradation.

Among the 23 action-oriented global targets for urgent action over the decade to 2030, several are related to the Tengchong study and the derived recommendations in the following ways.

1) The application of TEEBAgriFood approach in one of the national "Green is Gold" Practice Innovation Bases to inform sustainable policymaking at local and national levels directly contributes to Target 14 on the integration of biodiversity and its multiple values into policies, regulations, planning and development processes within all levels of government.

2) The overall study recommendations directly contribute to Target 10 on increasing the application of biodiversity friendly agriculture practices for the resilience and long-term efficiency and productivity of these production systems and to conserving and restoring biodiversity and maintaining nature's contribution to people.

3) The recommendation on taking multiple measures to reduce water pollution from agricultural chemicals use support Target 7 on reducing excess nutrients lost to the environment and reducing risk from pesticides that are harmful to biodiversity and ecosystem functions and services.

4) Encouraging managing methane emission in rice cultivation and livestock breeding and apply for funding support from CCER trading system is in line with Target 19 on increasing financial support from all resources including finding synergies of finance targeting the biodiversity and climate crises.

5) Advice on the need to think carefully about the relationship between conservation and development based on local conditions is aligned with the principles of the management of area-based conservation measures identified in Target 3, that is to ensure any sustainable use is fully consistent with conservation outcomes.

6) Advice on increasing the economic motivation for the change subjects (business, cooperatives and houesholds) by unlocking the potential of the consumption of green agricultural products (organic, green, etc.) is consistent with Target 16 on encouraging and enabling people to make sustainable consumption choices by improving education and access to relevant and accurate information and alternatives.

The Framework's implementation also considers the interlinkages between biodiversity and health and the three objectives of the Convention, aiming to sustainably balance and optimize the health of peoples, animals, plants and ecosystems. By accounting the health costs from exposure to agricultural pollutants in air and water as well as consumption of agricultural products, the Tengchong study adds one dimension into the environmental decision-making equation, the health of people.

The recommendations were formulated taking into account the principle of right to development (enable responsible and sustainable socioeconomic development that, at the same time, contributes to the conservation and sustainable use of biodiversity), recognizing the need for collective efforts (mobilize support from consumers and agricultural practitioners in addition to government), and also aiming at enhancing synergies between the CBD and the Paris Climate Agreement. The use of study results to inform decision making and raise awareness at various levels and through multiple channels and platforms (as explained in section 12.2) will encourage the use of information from transformative and transdisciplinary science-policy interface studies in the communication, education, awareness-raising and uptake of the diverse values of biodiversity and nature's contribution to people.

Box 2. The CBD COP15 side event "Recognizing and managing the value of nature's contribution to people through food systems transformation"

Amid CBD COP15 negotiations, UNEP, China, and the EU hosted an event highlighting the importance of sustainable agriculture and food systems transformations in halting biodiversity loss and restoring degraded ecosystems. Public and private sectors from countries and regions voice their support for strengthening the recognition and management of nature's contributions to people for sustainable and resilient agri-food systems in the post-2020 biodiversity conservation agenda.

Mr. Runqiu Huang, President of the COP15 and Minister of Ecology and Environment of China, and Ms. Christianne van der Wal-Zeggelink, Minister for Nature and Nitrogen Policy, Netherlands were present and made remarks at the event, highlighting the work of TEEB critical in supporting better-informed decisions and transition to nature-inclusive food systems. Representatives from governments, international organizations, academia, business, and civil society contributed vivid discussions and interactions around how making the economic case for pro-nature policies to achieve food system systems transformations is aligned with the Post-2020 Global Biodiversity Framework, including the need for metrics and framework, and challenges and opportunities ahead. The event was attended by more than 200 participants on the site and more via the internet.

Documents related to the event can be found at https://teebweb.org/our-work/agrifood/country-implementation-agrifood/eupi2019/china-eupi/valuing-natures-contributions-through-food-system-transformation/

Pillar 6. Public dissemination and social media outreach

The project has also made efforts to publicize the concept of the TEEBAgriFood framework and key information from the assessment through social and conventional media, including the blog pieces and publicity video issued as part of the UNEP China's social campaign on World Environment Day 2022, and Policy Briefs disseminated at the CBD COP15.

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