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Evaluation of the sustainable development level of grain family farms in main grain-producing areas based on agricultural multi-function: a case study of Hunan Province in China

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Introduction: Grain family farms play an important role in promoting agricultural modernization and rural revitalization in China. Taking Hunan Province as an example, based on survey data from 400 grain family farms and agricultural multi-function theory, 24 specific indicators were selected from three dimensions-economic benefits, social benefits, and ecological benefits-to construct an evaluation system for the sustainable development level of grain family farms.

Methods: The entropy weight TOPSIS method was used to measure the sustainable development level of grain family farms in Hunan Province, and the obstacle factor diagnosis model was used to explore the main obstacle factors affecting the sustainable development of grain family farms.

Results: (1) The sustainable development level of grain family farms in Hunan Province was classified as good overall with respect to the classification criteria of existing relevant studies, but there were comparative differences in each dimension among the four regions (central Hunan, northern Hunan, southern Hunan, and western Hunan) of Hunan Province. (2) According to the diagnosis and analysis results of the obstacle degree, the top six obstacle factors affecting the sustainable development level of grain family farms in Hunan Province were the effective use of water resources, soil protection, and improvement efforts, the number of agricultural ecological culture inheritance activities, carbon emission management, the number of jobs provided for farmers, and adaptability to external environmental changes.

Discussion: Relevant policies and systems should be formulated based on local conditions to enhance the integrity and synergy of the development of grain family farms in Hunan Province and to enhance the sustainable development ability of grain family farms in Hunan Province.

KEYWORDS

agricultural multi-function, grain family farm, sustainable development, evaluation system, China

1 Introduction

Compared with other agricultural management models, family farm with family operation as the main feature can make timely and efficient production decisions according to weather changes and plant and animal growth, which is highly adapted to the agricultural production characteristics (Newsome et al., 2024; Verger and Le Bars, 2024). More critically, it is a community of interests linked by blood and marriage relationship, which can minimize the labor management cost, and avoid the difficult problem of labor quality supervision, so as to improve production efficiency and obtain good economies of scale (Ge and Li, 2023; Kurlavicius et al., 2024). Therefore, family farm is the preferred agricultural management mode in most countries in the world, and has become the basic most efficient management body of modern agriculture. Currently, there are 608 million family farms worldwide, producing more than 80% of the world's food (Liu, 2024; Xue et al., 2024). There is no doubt that the sustainable development of family farms plays an important role in global food security.

Under the background of agricultural marketization and globalization, Chinese agriculture falls into the "small farmer dilemma", which delays the pace of China's agricultural and rural modernization. As the inheritance, innovation and perfection of the household contract responsibility system, Chinese family farm is a new agricultural management model suitable for Chinese agricultural production characteristics and in line with China's agricultural development goal at the present stage (Wu, 2022; Du, 2024), which can help Chinese agriculture get rid of the dilemma to accelerate the construction of a powerful agricultural country in the new era. In 2024, China noted that "the production and operation level of family farms and farmers' cooperatives should be improved, and their capacity to serve and drive small farmers needs to be enhanced."[1] According to statistics from Ministry of Agriculture and Rural Affairs of China, as of May 2023, nearly 4 million family farms had been included in the national list of family farms under management, an increase of approximately 10.66 times compared with the number (343,000) in 2015. However, at the same time as this rapid growth in number, according to the investigations of the authors, Chinese grain family farms are facing practical problems such as weak market profitability, insufficient participation in social responsibility, and insufficient ecological protection and restoration, which hinders their sustainable development. It is necessary to adopt reasonable and feasible methods to objectively quantify the sustainable development level of Chinese grain family farms and systematically explore the deep-seated reasons that hinder their sustainable development.

Therefore, considering the important strategic position of food security in major grain-producing areas, studying the overall level and regional differences and obstacle factors of the sustainable development of family grain farms in major grain-producing areas of China from the perspective of agricultural multi-function can promote progress in the sustainable development level of grain family farms in major grain-producing areas. It can also provide experience for the development of grain family farms in non-major grain-producing areas to jointly build the grain foundation for the development of China's agricultural modernization in the new era.

By combining the scholars' relevant researches, it was found that there are few studies on the sustainable development of family farms. Based on the scope of the study, the few existing studies on this topic have mainly focused on two perspectives: the whole country and the region of the country. In terms of the perspective of the whole country, considering that the development of family farms in American, France, Japan and China is representative in the world, we mainly review the research status of sustainable development of family farms in the above four countries. Some scholars found the sustainable development of American family farms is due to its efficient production system, diversified economic model, positive environmental protection measures, the use of renewable energy, the contribution to social welfare and the extensive application of high technology. Therefore, they constructed an evaluation system to assess the level of sustainable development of farms from the aspects of production efficiency, economic diversity, ecological protection, energy use, social welfare and agricultural technology application. The results showed that the level is close to excellent. This provides valuable experience for the development of Chinese family farms, and helps to promote China's agricultural modernization and the implementation of Chinese rural revitalization strategy (Effland, 2022; Lacy et al., 2023). Some scholars constructed an index system from the aspects of production efficiency, environmental management, economic feasibility, social acceptance and agricultural innovation to evaluate the level of sustainable development of French family farms. They found that, along with American family farms, French family farms are among the world's leaders (Kahindo and Blancard, 2022; Lucas and Gasselin, 2022). Some scholars constructed an index system from government support, agricultural cooperative organization support, agricultural scientific institution support, land transfer mechanism, brand management to evaluate the sustainable development level of Japanese family farms. They found that Japanese family farms were relatively successful in sustainable development. The development experience of Japanese family farms has important reference significance for the future development of Chinese agriculture (Kurisu, 2023; Tanaka et al., 2023). Some Chinese scholars constructed an index system from four aspects: labor quality, operation scale, economic efficiency, and market access ability which they used to evaluate the level of sustainable development of Chinese family farms. The results show that the sustainable development index of Chinese family farms is 0.25, which is low. They found that there are obvious shortcomings in the development of Chinese family farms, such as, low labor quality, insufficient marketization level and poor income effect, which hinder their sustainable development to some extent (Li, 2022; Zhao et al., 2022). Different from Li and Zhao et al.' research results, some Chinese scholars constructed an indicator system from government support, social services, technological innovation, and environmentally friendly behavior. They used the entropy weight method to evaluate the level of sustainable development of Chinese family farms, and calculated that the sustainable development index was 0.8, which is high. They advocate that Chinese family farms have been strongly supported by the government, and can realize intensive management and effective allocation of agricultural land resources under a certain

1 Available at: https://www.gov.cn/gongbao/2024/issue_11186/202402/content_6934551.html

scale. They have strong vitality, strong competitiveness and modern concepts, and have certain advantages in operation scale, decision-making management, safety precautions, technology application, brand benefits and other aspects (Liu, 2024; Zhang et al., 2024).

In terms of the perspective of the region of the country, considering the compatibility of the existing literature with the research topic of this paper, we mainly review the research status of the sustainable development of family farms in China's major grain producing areas (Heilongjiang, Shandong, Henan, Sichuan, Jiangsu, Hebei, Jilin, Hunan, Hubei, Anhui, Inner Mongolia, Jiangxi). According to the economic and social development and geographical location of each province, we only review the research on the sustainable development of family farms in four of the 13 major grain-producing areas—Liaoning, Sichuan, Jiangsu and Hunan. Some scholars selected 18 representative indicators from the four levels of economic benefit, resource utilization, ecological optimization and basic security to construct an evaluation index system, and adopted entropy method to objectively evaluate the sustainable development level of family farms in Liaoning Province. They found a level value of 0.45. Economic benefit, resource utilization, ecological optimization and basic security show a good development trend, but the contribution of resource utilization and ecological optimization to the overall development level is low at present (Li et al., 2017; Dai, 2022). Some constructed an index system from scale management, economic benefits, land transfer, professional skills, and policy support to assess the sustainable development level of family farms in Sichuan Province. They believe that the development of family farms in Sichuan Province has problems such as high land transfer costs and weak professional skills (Fan, 2016; Yang and Zhuang, 2022). They build an index system from agricultural technology innovation, agricultural product quality and safety, market competitiveness, and social responsibility to assess the sustainable development level of family farms in Jiangsu Province. They argued that family farms in Jiangsu Province had problems such as lack of technological innovation ability and market competitiveness, which hindered the sustainable development of family farms (Liu et al., 2020; Li and Xu, 2021). As a main grain-producing area, Hunan Province undertakes the important mission of China's food security. It is a fact that grain family farms bear the important task of grain production and supply in Hunan Province. Considering the level of social and economic development and geographical location, Hunan Province can be divided into four regions: central Hunan, northern Hunan, southern Hunan and western Hunan. From the three dimensions of economy, society and ecology, an evaluation system containing 28 specific indicators was constructed to evaluate the level of sustainable development of family farms in Hunan Province and its four regions. The results showed that the overall level of sustainable development of family farms in Hunan Province was close to ideal. For central Hunan, economic benefit is the first, but ecological benefit is the last. Social benefit of northern Hunan is the first. Ecological benefit is the first and social benefit the last in southern Hunan. Economic benefit of Western region is the lowest. The obstacles affecting the sustainable development of family farms in Hunan Province are concentrated in the economic dimension (Ji and Zeng, 2020; Tang, 2021).

In summary, existing studies on the sustainable development of family farms have focused on two main perspectives: the whole country and the region of the country, and there is a lack of research on the sustainable development of grain family farms based on agricultural multi-function. However, as an important pillar for ensuring food security, the sustainable development of grain family farms based on agricultural multi-function plays an important role in realizing the multi-coordination of food production, ecological protection and social services in agricultural ecosystems. By integrating ecological, economic and social functions, the sustainable development of grain family farms helps to maintain, not only the ecological balance and biodiversity in rural areas, but also the long-term stability of rural society, and it promotes the comprehensive improvement in agricultural sustainability. On this basis, this paper takes Hunan Province, one of the main grain-producing areas in China, as an example. Additionally, we use the entropy weight TOPSIS method to measure the sustainable development level of grain family farms. The obstacle factor model is used to further analyze the main obstacle factors to the sustainable development of grain family farms.

2 Theoretical basis

The concept of sustainable development was first used to explain the scarcity of natural resources and environmental damage (Wang G. Y. et al., 2023; Li et al., 2024; Niewiadomski and Stachowiak, 2024). Since the 1980s, with the formation and prevalence of the concept of sustainable development in the world, the theory of sustainable development has been gradually established and improved, and its connotation and essence can be revealed from the following three main directions (Li, 2023; Sasongko et al., 2024). Firstly, the direction of economics. It takes regional development, production capacity layout, economic structure optimization, physical supply and demand balance as the basic content. Secondly, the direction of sociology. It takes social development, social distribution, interest balance as its basic content. Thirdly, the direction of ecology. It takes ecological balance, nature protection, sustainable utilization of resources and environment as the basic content. Therefore, the theory of sustainable development is based on the current socio-economic and technological conditions, and mainly relies on scientific and technological progress, institutional innovation and institutional reform to achieve the coordinated development of economy, society and ecology (Deng et al., 2017; Biswas et al., 2021). Its fundamental task is the effective management and protection of natural resources and ecological environment, and in the process of achieving economic growth and development, it not only pays attention to the improvement of product quantity, quality and efficiency, but also pays more attention to the coordination of economic benefits, social benefits and ecological benefits, and promotes the sustainable development of economy, society and ecology (Shi et al., 2019; Hao et al., 2022). Agriculture sustainable development is an important part of the theory of sustainable development, which should also pursue the coordinated development of economic benefits, social benefits and ecological benefits. There is no doubt that the benefits cannot be obtained without the effective play of the functions. Therefore, agriculture sustainable development depends on the effective use of agricultural multi-function.

Agricultural multi-function is a comprehensive concept of agricultural development that emphasizes the multiple functions of agriculture, covering the functions of the economy, society, ecology and other aspects. Agriculture multi-function means that agriculture has the function of producing food and plant fiber, but also has the functions of environment, society, food security, economy and culture (Yuan et al., 2023; Peng et al., 2024). The function carried by agriculture should be expanded from a single production function to multiple functions such as economy, ecology and culture (Zhang and Chen, 2022, 2023). Rural development should be promoted from a single production function to a comprehensive development of economic, social and environmental functions, beyond the traditional production activities of agricultural products, to formulate a richer and diversified agricultural practice activities (Shi, 2023; Farley and Schmitt, 2024). Agriculture is not only a simple act of producing food and agricultural products which can stabilize the economy, but also a complex system that has a profound impact on society and the environment (Md Hamdan et al., 2024; Shen et al., 2024). Based on this, we focus on economic, social and ecological functions of agriculture.

First, from the perspective of economic functions, agricultural multi-function emphasizes that agriculture makes multiple contributions to the economic system and obtains good economic benefits (Liu et al., 2020; Namany et al., 2022). Agriculture not only meets humans' need for food but also plays an important role in creating job opportunities and driving rural economic growth. By promoting the diversification of agricultural products and moving up the value chain, agriculture can be a comprehensive economic engine that contributes to the prosperity of rural communities and promotes rural economy development (Ren et al., 2015; Ferrari et al., 2022). Second, from the perspective of social functions, agricultural multi-function focuses on cultivating and inheriting rich rural culture and traditional customs, highlighting the uniqueness of rural communities, helping to enhance farmers' pride and identity, strengthening their sense of belonging to rural communities, and promoting cohesion and social harmony in rural communities. Finally, from the perspective of ecological functions, agricultural multi-function is committed to promoting sustainable agriculture and maintaining agricultural ecological security (Wang D. D. et al., 2023; Lee and He, 2024). Adopting eco-friendly agricultural methods, such as organic agriculture and farmland ecosystem management, helps to reduce the pressure on soil, water resources and ecosystems, achieve efficient use of resources, and promote ecological balance and biodiversity protection, so as to promote the sustainable development of agriculture (Fan et al., 2023; Seremesic et al., 2024).

As a practical embodiment of agricultural multi-function, according to agricultural multi-function, grain family farms have rich economic, social and ecological functions (Taysom, 2023; Kurlavicius et al., 2024). In terms of economic functions, grain family farms have injected vitality into the rural economy. By diversifying the production and processing of agricultural products, they have increased the added value of agricultural products, created job opportunities and promoted economic growth in rural areas. Farmers engage in agricultural production on grain family farms to earn not only their own livelihood but also income through market sales so as to contribute to the rural economy development (He and Wang, 2023; Dona et al., 2024). In terms of social functions, grain family farms carry the mission of traditional culture and community cohesion. On grain family farms, farmers inherit farming skills and living wisdom passed down from generation to generation, and they carry forward rural cultural traditions. This not only strengthens the cohesion of rural communities but also promotes social harmony and stability so as to achieve good social benefits (Li Z. J. et al., 2023; Sambuichi et al., 2024). In terms of ecological functions, grain family farms have adopted eco-friendly agricultural production methods. Through organic agriculture and farmland ecosystem management, the pollution of soil and water resources caused by fertilizers and pesticides is reduced, and the health of the ecological environment is protected. At the same time, grain family farms promote soil protection and regeneration through reasonable farming rotation and land management and maintain the balance and stability of farmland ecosystems so as to achieve good ecological benefits (Azima and Mundler, 2023; Zhu et al., 2024).Therefore, based on agricultural multi-function, we construct an evaluation index system of the sustainable development level of grain family farms from three aspects: economic function, social function and ecological function, including three dimensions: economic benefit, social benefit and ecological benefit (Figure 1).

At present, the methods used by global scholars to evaluate development level mainly include factor analysis method, analytic hierarchy process and entropy weight method, which has been widely used in the level evaluation of many industries. In terms of factor analysis method, based on financial sustainable development theory, the index data of commercial banks are selected, and factor analysis method are used to measure and rank the sustainable development level of commercial banks (He and Li, 2012; Bayrakdaroglu and Yalçin, 2013). The index system for evaluating the urban sustainable development level is constructed from several aspects: economy, environment, resources, social development and population. By selecting factor analysis method, more original indexes can be synthesized into several fewer indexes through dimensionality reduction (Gai et al., 2014; Guzman, 2020). From the point of view of the sustainable development, the evaluation system of sustainable development index of rural economy is constructed, and the sustainable development ability of rural economy is evaluated and analyzed by factor analysis (Liu, 2015; Padda and Hameed, 2018). In terms of analytic hierarchy process, based on energy economy theory, a comprehensive evaluation system was constructed to measure energy sustainability by integrating the subsystems of economy, society, institution and environment, and the analytic hierarchy process was used to evaluate energy sustainability from 2001 to 2011 (Xiang et al., 2016; Zaharia et al., 2019). The sustainable development index of marine economy is constructed, and four indexes including regional development, marine economy, marine resources and environment, and marine talents and technology are selected to establish the sustainable development index system of marine economy, and the analytic hierarchy process is used to calculate the weight of each index (Li et al., 2015; Karahalios, 2020; Lim et al., 2024). In terms of entropy weight method, the evaluation index system and entropy weight evaluation model of sustainable

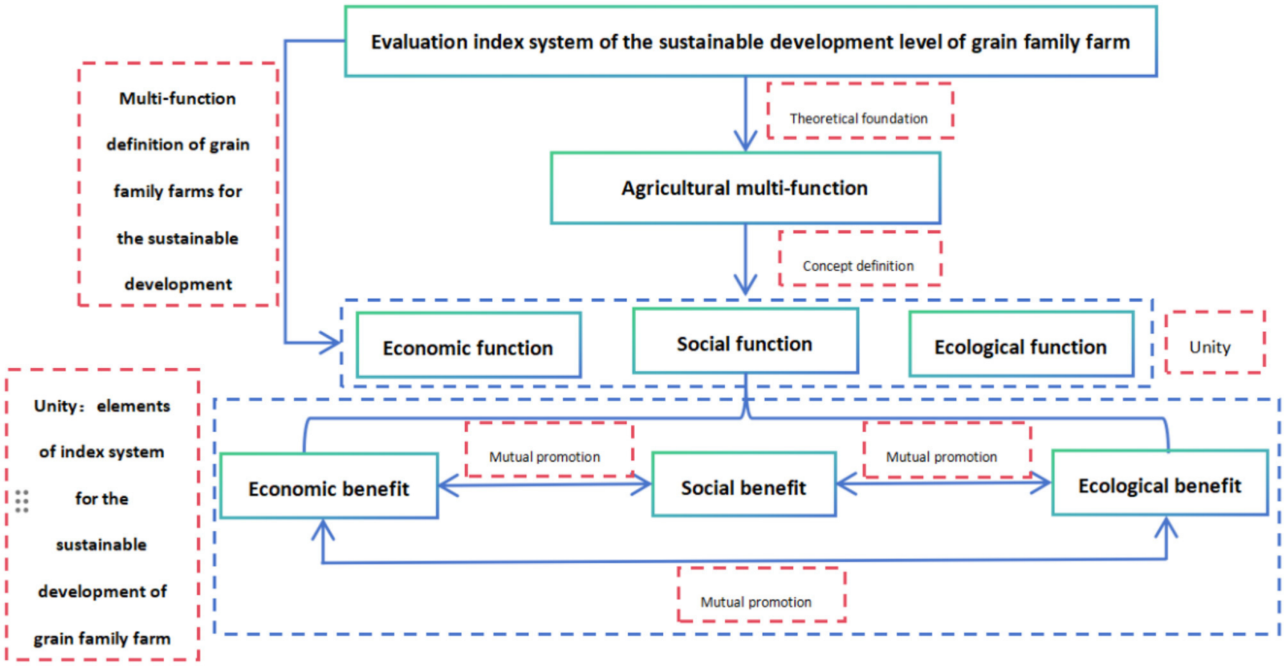

FIGURE 1
Theoretical model of evaluation index system of the sustainable development level of grain family farm. (1) The red dotted boxes and their texts explain the meaning of the arrow and blue dotted boxes. (2) The elements inside the blue dotted box are a unity. (3) Green solid boxes mean separate elements.

development of regional innovation ecosystem are constructed, and the obstacle degree model is used to analyze the constraints affecting sustainable development (Zhang and Zeng, 2021; Li and Cai, 2022). Evaluation indexes were constructed from several aspects: agricultural input level, agricultural output level, rural social development level and agricultural sustainable development level. The entropy weight TOPSIS comprehensive evaluation method was used to estimate the agricultural modernization development level (Liu and Zhang, 2021; Wang and Tang, 2023; Li Z. J. et al., 2023).

After reviewing the above three methods, it is found that most scholars choose to use entropy weight method to carry out level evaluation research. The possible reason is that compared with other methods, the results obtained by entropy weight method are more objective and accurate. Based on this, we use entropy weight method to determine the weight of each indicator and avoid the influence of human factors on the weight setting. Then we use TOPSIS method to sort the evaluation objects according to these weights, and finally get the relative merits and demerits of the evaluation results, making the evaluation process more systematic and scientific.

3 Materials and methods

3.1 Overview of the study area

As a major agricultural province and one of the major grain-producing areas in China, Hunan Province is rich in agricultural resources and has a long history of farming. Located in the middle of China, the province has a mountainous terrain, rich water systems and a mild and humid climate suitable for grain growth. Due to Hunan's abundant resources, the grain planting area is vast, and the output is stable. According to China's National Bureau of Statistics, the grain sown area of Hunan in 2023 was 11.77 million acres, exceeding the planned target by 0.017 million acres. In 2023, Hunan's total grain output was 30.68 million tons, an increase of 0.5 million tons over 2022, an increase of 1.7%, and standing above 30 million tons for four consecutive years, making contribution to ensuring China's national food security. Hunan is playing a positive role in China's food security. Based on a comprehensive consideration of geographical location, landform and economic and social development, the following research areas were selected: central Hunan, northern Hunan, southern Hunan and western Hunan. Central Hunan (red zone) includes Changsha, Zhuzhou, Xiangtan, Loudi, and Shaoya. Northern Hunan (yellow zone) includes Yueyang, Yiyang, and Changde. Southern Hunan (purple zone) includes Chenzhou, Yongzhou and Hengyang. Western Hunan (blue zone) includes Xiangxi Tujiazu and Miaozu Autonomous Prefecture, Huaihua, and Zhangjiajie (Figure 2).

3.2 Data source

The data in this study were collected from a questionnaire survey of grain family farms of cities of four regions (central Hunan, northern Hunan, southern Hunan and western Hunan) in Hunan Province conducted from July to August 2023. A random

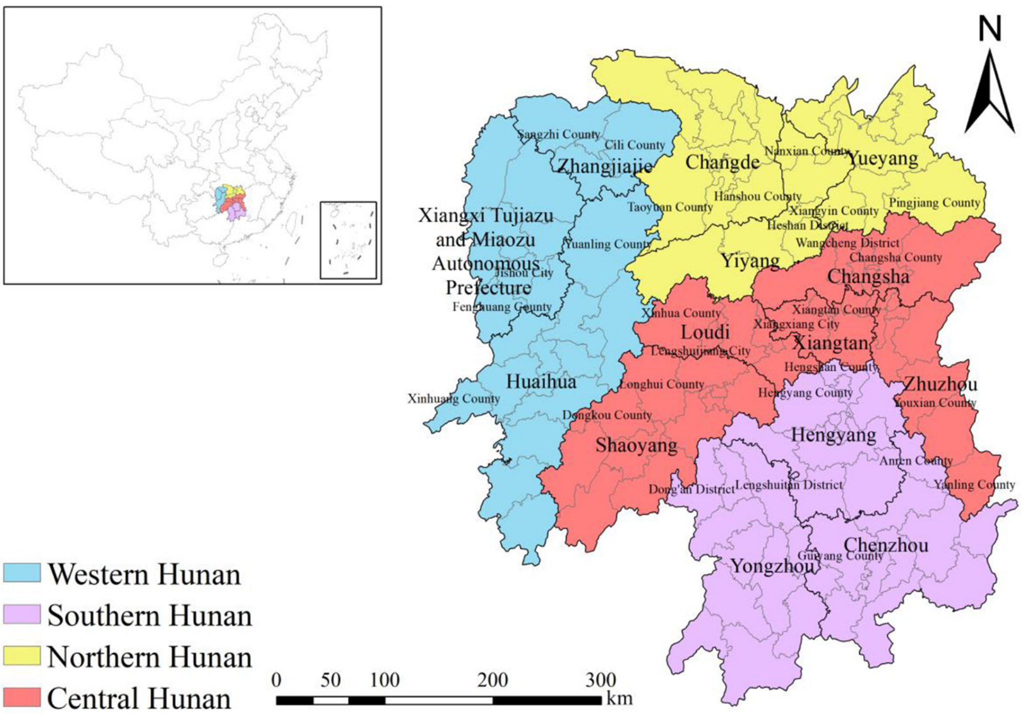

FIGURE 2
The map of the study area.

sampling method was adopted to randomly select two counties (cities) in each city (Table 1), two towns (townships) in each county (city), and seven to eight grain family farms in each town (township) to carry out online or offline questionnaire surveys. A total of 420 questionnaires were sent out in this survey, and 400 valid questionnaires were recovered, for an effective response rate of 95.24%.

3.3 Index system construction

Based on agricultural multi-function, the sustainable development level of grain family farms is taken as the target layer, which includes three parts, i.e., economic benefits, social benefits and ecological benefits, that is, the criterion layer (Li Y. Y. et al., 2023; Zeng et al., 2024). Following the principles of objectivity, operability, comprehensiveness and sustainability, 24 specific indicators were selected to construct the index layer (Table 2).

Our questionnaire sets these questions (indicators), such as the ability to adapt to the external environmental changes and market competitiveness. Each question (indicator) sets five options, such as very weak, weak, general, strong, very strong. We sent questionnaires to grain family farmers and asked them to fill them out according to the actual situation of their farms. In order to avoid the influence of this subjective factor on the evaluation results, we specially introduced the weights determined by the entropy weight TOPSISI method to make the evaluation results more objective and fair. The reason is that entropy weight TOPSISI method combines information entropy and TOPSIS method to allocate weight and reduce the influence of subjective judgment.

In terms of economic benefits, eight indicators were used to measure the economic benefits of grain family farms: the grain planting area, the number of farmer jobs provided, agricultural innovation and technology promotion, participation in the agricultural value chain, income from agricultural market sales, income from agricultural tourism and rural experience, the ability to adapt to external environmental changes and market competitiveness. An increase in the grain planting area improves a farm's output and income level but also increases the farm's cost and risk, which must be taken into account when the farm is making operational decisions (Fu and Li, 2024; Pérez-Piza et al., 2024). Farm operators need to comprehensively consider the benefits, costs, risks and returns and formulate a reasonable grain planting area plan to ensure the stable and sustainable development of the farm economy. Providing farmers with jobs can increase the labor force of grain family farms, improve production efficiency and out-put, enhance the productivity and economic vitality of grain family farms, help farmers increase their income, reduce the risk of farmers returning to poverty, promote the development of related industries, form a virtuous circle of the rural economy and achieve the sustainable development of economic benefits (Dai et al., 2024; Tuliende et al., 2024). Through agricultural innovation and technology promotion as well as the adoption of advanced technologies and innovative methods, farms can improve production efficiency and product quality and reduce production costs, thus strengthening the income effect. At the same time, active participation in the agricultural value chain, including planting,

TABLE 1 Distribution of counties in the survey area.

Study area	City	County	Number of questionnaires sent
Central Hunan	Changsha	Wangcheng District	16
		Changsha County	14
	Zhuzhou	Youxian County	15
		Yanling County	15
	Xiangtan	Xiangtan County	16
		Xiangxiang City	14
	Loudi	Xinhua County	15
		Lengshuijiang City	15
	Shaoyang	Longhui County	15
		Dongkou County	15
Northern Hunan	Yueyang	Xiangyin County	14
		Pingjiang County	16
	Yiyang	Nanxian County	16
		Heshan District	14
	Changde	Taoyuan County	15
		Hanshou County	15
Southern Hunan	Chenzhou	Guiyang County	16
		Anren County	14
	Yongzhou	Lengshuitan District	16
		Dong'an County	16
	Hengyang	Hengyang County	14
		Hengshan County	14
Western Hunan	Xiangxi Tujiazu and Miaozu Autonomous Prefecture	Jishou City	14
		Fenghuang County	14
	Huaihua	Yuanling County	16
		Xinhuang County	16
	Zhangjiajie	Cili County	15
		Sangzhi County	15

processing, marketing and other links, can help expand the market share of agricultural products, expand sales channels, and further promote the steady growth of the farm economy. Income from sales in agricultural product markets provides a stable source of income for farms, while income from agricultural tourism and rural experience adds diversified income channels for farms, which can revitalize the farm's economy (Savickiene and Miceikiene, 2018; Boudedja et al., 2024). This diversified source of income not only contributes to the economic resilience and sustainability of farms but also provides consumers with the opportunity to interact with nature and agriculture, driving the development of rural tourism. Effective adaptability to the external environment enables farms to flexibly adjust their production strategies, cope with challenges such as climate change and fluctuating market demand, and ensure sustainable and stable production. At the same time, having strong market competitiveness can cause a farm to stand out in fierce market competition, increase its sales opportunities and profits, and ultimately achieve economic growth.

In terms of social benefits, we hold that social benefits include eight indicators: the promotion of rural neighborhood ties and a sense of community, the frequency of rural education and skill training, the intensity of social services and support, the frequency of agricultural temple activities, participation in rural governance, the degree of social mutual assistance and cooperation, the improvement degree of social health and life quality, and the construction of rural civilization and public cultural space. The promotion of rural neighborhood ties and a sense of community not only enhances the interaction and cooperation between grain family farms and surrounding communities, promotes information exchange and resource sharing, and enhances the social influence of farms, but also helps to enhance the mutual assistance and support between farmers and farms, jointly cope with challenges, and improve the risk resistance of farms to promote the sustainable development and common prosperity of rural communities. The increase in the frequency of rural education and skills training enhances the knowledge level and skills of farm operators, improves their ability in agricultural production and management, and helps improve the production efficiency and competitiveness of farms. The strengthening of social services and support provides farm operators with more help and resources to enhance the resilience of farms to risks, improve the living conditions of rural communities, and enhance farmers' sense of wellbeing and belonging, thus promoting the stability and development of rural communities and maintaining harmony and tranquility in rural areas (Kostov et al., 2018; de Oliveira et al., 2024). Agricultural temple activities not only enriches rural cultural life but also enhances the sense of identity of farmers, enhances the cohesiveness and cooperation between farms and farmers as well as rural communities, and promotes the progress and development of rural society. Participation in rural governance affects farmers' understanding of and participation in policies, promotes order and stability within rural communities, and is conducive to enhancing the development potential of farms. The improvement in the degree of social mutual assistance and cooperation enhances the sense of cooperation and unity between farms and farmers, promotes the sharing and reciprocity of resources, drives family farms to increase production and strengthens the cohesion within rural communities (Wuepper et al., 2021; Guevara-Hernández et al., 2024). The

TABLE 2 Index system for the sustainable development level of grain family farms.

Target layer	Criterion layer	Index layer	Indicator quantization	Indicator trend
Level of sustainable development of grain family farms	Economic benefits	Grain planting area (C_1)	<50 acres = 1, 50–100 acres = 2, 100–150 acres = 3, 150–200 acres = 4, 200 acres or more = 5	+
		Number of farmer jobs provided (C_2)	<50 jobs = 1, 50–100 jobs = 2, 100–150 jobs = 3, 150–200 jobs = 4, 200 jobs or more= 5	+
		Agricultural innovation and technology promotion (C_3)	Smaller = 1, small = 2, general = 3, large = 4, larger = 5	+
		Participation in agricultural value chains (C_4)	Very poor = 1, poor = 2, general = 3, good = 4, very good = 5	+
		Income from agricultural market sales (C_5)	<200,000 yuan = 1, 200,000– 500,000 yuan = 2, 500,000–800,000 yuan = 3, 800,000–1,100,000 yuan = 4, more than 1,100,000 yuan = 5	+
		Income from agricultural tourism and rural experience (C_6)	<100,000 yuan = 1, 100,000–200,000 yuan = 2, 200,000–300,000 yuan = 3, 300,000–400,000 yuan = 4, more than 400,000 yuan = 5	+
		Ability to adapt to external environmental changes (C_7)	Very weak = 1, weak = 2, general = 3, strong = 4, very strong = 5	+
		Market competitiveness (C_8)	Very weak = 1, weak = 2, general = 3, strong = 4, very strong = 5	+
	Social benefits	Promotion of rural neighborhood ties and a sense of community (C_9)	Very weak = 1, weak = 2, general = 3, strong = 4, very strong = 5	+
		Frequency of rural education and skill training (C_{10})	None = 1, one time = 2, two times = 3, three times = 4, four times and more = 5	+
		Intensity of social services and support (C_{11})	Smaller = 1, small = 2, general = 3, large = 4, larger = 5	+
		Frequency of agricultural temple activities (C_{12})	None = 1, one time = 2, two times = 3, three times = 4, four times and more = 5	+
		Participation in rural governance (C_{13})	No participation = 1, occasional participation = 2, general = 3, frequent participation = 4, full participation = 5	+
		Degree of social mutual assistance and cooperation (C_{14})	Very poor = 1, poor = 2, general = 3, good = 4, very good = 5	+
		Improvement degree of social health and life quality (C_{15})	Smaller = 1, small = 2, general = 3, large = 4, larger = 5	+
		Construction of rural civilization and public cultural space (C_{16})	Very poor = 1, poor = 2, general = 3, good = 4, very good = 5	+
	Ecological benefits	Number of green production behaviors (C_{17})	None = 1, one type = 2, two types = 3, three types = 4, 4 types and more = 5	+
		Maintenance of biodiversity (C_{18})	Very poor = 1, poor = 2, general = 3, good = 4, very good = 5	+
		Implementation degree of organic agriculture (C_{19})	Very low = 1, low = 2, general = 3, high = 4, very high = 5	+
		Effective use of water resources (C_{20})	Very low = 1, low = 2, general = 3, high = 4, very high = 5	+
		Intensity of soil protection and improvement (C_{21})	Smaller = 1, small = 2, general = 3, large = 4, larger = 5	+

(Continued)

TABLE 2 (Continued)

Target layer	Criterion layer	Index layer	Indicator quantization	Indicator trend
		Number of agricultural ecological culture inheritance activities (C_{22})	None = 1, one time = 2, two times = 3, three times = 4, four times and more = 5	+
		Carbon emission management (C_{23})	Very poor = 1, poor = 2, general = 3, good = 4, very good = 5	+
		Status of ecological development planning (C_{24})	Very poor = 1, poor = 2, general = 3, good = 4, very good = 5	+

improvement in social health and life quality affects the happiness and life satisfaction of farmers and enhances the human capital and sustainable development ability of farms. The improvement in the construction of rural civilization and public cultural space enrich the spiritual and cultural life of rural communities, enhance the cultural heritage and soft power of communities, help to shape the good image of rural communities, and promote the progress and development of rural society.

In terms of ecological benefits, eight indicators were adopted to reflect ecological benefits: the number of green production behaviors, the maintenance of biodiversity, the implementation degree of organic agriculture, the effective use of water resources, the intensity of soil protection and improvement, the number of agricultural ecological culture inheritance activities, carbon emission management, and the status of ecological development planning. Increasing the number of green production behaviors can help reduce the use of chemical pesticides and fertilizers, reduce soil and water pollution, protect the ecological environment and biodiversity, promote soil health and water quality protection, and ultimately improve the ecological health level of farms. Good biodiversity maintenance helps to maintain ecological balance and promote the stable and healthy development of farmland ecosystems. The protection and restoration of diverse biological communities can improve the natural control capacity of farms, reduce the use of chemical pesticides, and reduce the pressure on agroecological systems. The implementation of organic agriculture can reduce the use of chemical pesticides and fertilizers, reduce the pressure on agricultural ecosystems, and promote the maintenance of ecological balance. The efficient use of water resources can reduce the waste and over-exploitation of water resources, promote the efficient recycling of water resources, and ensure the stable and sustainable development of farmland ecosystems (Silva et al., 2023; Casagrande et al., 2024). Active soil protection and improvement work can increase soil fertility and water retention capacity, improve the soil structure, and promote plant growth and ecosystem restoration and development. Holding activities to pass on agricultural ecological culture will help farmers pass on traditional agricultural knowledge, enhance ecological awareness, and promote the inheritance and development of ecological culture. The effective management of carbon emissions will help reduce greenhouse gas emissions, reduce the impact of climate change, and contribute to the stability of the environment and ecosystem. Scientific and reasonable ecological development planning can guide the development of grain family farms in the direction of sustainable development, optimize the agricultural production structure, improve resource utilization efficiency, and enhance the ecological effect level of farms.

3.4 Research methods

3.4.1 Entropy weight TOPSIS method

The entropy weight TOPSIS method has been widely used in various research fields for evaluating indexes (Wang and Dong, 2023; Kumar et al., 2024). The reasons are as follows: first, it can comprehensively consider the relative importance of each indicator in the index system, effectively reflect the indicator information, and objectively calculate the weight of each indicator; second, it can make positive ideal solutions and negative ideal solutions have certain stability, obtain better comparable results, and improve the credibility of the results. We use the entropy weight TOPSIS method to confirm and analyse the survey data with reference to the results of existing research (Li Y. et al., 2023; Kumar et al., 2024).

(1) Standardized processing of index data

Positive indicators:

$$X'_{ij} = \frac{X_{ij} - \min(X_j)}{\max(X_j) - \min(X_j)} \tag{1}$$

Negative indicators:

$$X'_{ij} = \frac{\max(X_j) - X_{ij}}{\max(X_j) - \min(X_j)} \tag{2}$$

In Equations 1, 2, $X_{ij}{}'$ is the normalized value, and X_{ij} is the original value (the value of the initial data obtained through the questionnaire) of the i-th indicator for the$j$-th farm. $i = 1, 2, \cdots, m$ (m is the number of indicators), and$j = 1, 2, \cdots, n$ (n is the number of farms). Following the research of Wang G. Y. et al. (2023), the data coordinates are translated to 0.01.

(2) Calculate the variation size of the index (p_{ij})

$$p_{ij} = \frac{Y_{ij}}{\sum_{i=1}^{n} Y_{ij}} \tag{3}$$

In Equation 3, $Y_{ij} = X_{ij}{}' + A$, and A is the translation distance.

(3) Calculate the information entropy of each indicator (E_i)

$$E_i = -\frac{1}{\ln(n)} \sum_{i=1}^{n} p_{ij} \ln p_{ij} \tag{4}$$

In Equation 4, $E_i \geq 0$ if $p_{ij} = 0, E_i = 0$

(4) Determine the weight of each indicator (W_i)

TABLE 3 Evaluation criteria for the sustainable development level.

	General	Good	Ideal
S_j	[0, 0.3)	[0.3, 0.6)	[0.6, 1)

$$W_i = \frac{1 - E_i}{\sum_{i=1}^{m} (1 - E_i)} \tag{5}$$

(5) Construct the weighted normalization matrix of evaluation indicators (Z)

$$Z = Y \cdot W = \left[z_{ij}\right]_{m \times n} \tag{6}$$

In Equation 6, the normalization matrix $Y = \left[p_{ij}\right]_{m\times n}$, where W is the weight vector established by the entropy weight method. z_{ij} is the index value of indicator i after weighted normalization of the j-th farm.

(6) Determine the positive ideal solution (Z^+) and negative ideal solution (Z^-)

$$Z^+ = \left\{ \max z_{ij} \,|i = 1, 2, 3, \cdots, m \right\} = \left\{ Z_1^+, Z_2^+, \cdots, Z_m^+ \right\} \tag{7}$$

$$Z^- = \left\{ \min z_{ij} \,|i = 1, 2, 3, \cdots, m \right\} = \left\{ Z_1^-, Z_2^-, \cdots, Z_m^- \right\} \tag{8}$$

(7) Calculate the Euclidean distance

$$D_j^+ = \sqrt{\sum_{i=1}^{m} \left(Z_i^+ - Z_{ij}\right)^2} \tag{9}$$

$$D_j^- = \sqrt{\sum_{i=1}^{m} \left(Z_i^- - Z_{ij}\right)^2} \tag{10}$$

(8) Calculate the proximity degree

$$S_j = \frac{D_j^-}{D_j^+ + D_j^-} \tag{11}$$

In Equation 11 (see procedure number eight), $0 \leq S_j \leq 1$, and the larger the value of S_j is, the closer it is to the maximum value, which means that the sustainable development performance of grain family farms is greater; otherwise, the sustainable development performance of grain family farms is lower. With reference to the results of existing research (Li Y. et al., 2023; Zhang, 2023; Li and Li, 2023), three intervals are created in this study (Table 3).

TABLE 4 Information entropy and weight of the indicators.

Indicator name	Information entropy	Weight
Grain planting area (C_1)	0.9796	0.0862
Number of farmer jobs provided (C_2)	0.9546	0.1913
Agricultural innovation and technology promotion (C_3)	0.9662	0.1424
Participation in agricultural value chains (C_4)	0.9709	0.1226
Income from agricultural market sales (C_5)	0.9788	0.0894
Income from agricultural tourism and rural experience (C_6)	0.9799	0.0847
Ability to adapt to external environmental changes (C_7)	0.9636	0.1533
Market competitiveness (C_8)	0.9691	0.1302
Promotion of rural neighborhood ties and a sense of community (C_9)	0.9704	0.1360
Frequency of rural education and skill training (C_{10})	0.9661	0.1559
Intensity of social services and support (C_{11})	0.9656	0.1583
Frequency of agricultural temple activities (C_{12})	0.9717	0.1303
Participation in rural governance (C_{13})	0.9741	0.1191
Degree of social mutual assistance and cooperation (C_{14})	0.9775	0.1034
Improvement degree of social health and life quality (C_{15})	0.9809	0.0881
Construction of rural civilization and public cultural space (C_{16})	0.9763	0.1090
Number of green production behaviors (C_{17})	0.9864	0.0513
Maintenance of biodiversity (C_{18})	0.9689	0.1172
Implementation degree of organic agriculture (C_{19})	0.9674	0.1226
Effective use of water resources (C_{20})	0.9577	0.1592
Intensity of soil protection and improvement (C_{21})	0.9500	0.1882
Number of agricultural ecological culture inheritance activities (C_{22})	0.9640	0.1356
Carbon emission management (C_{23})	0.9619	0.1435
Status of ecological development planning (C_{24})	0.9781	0.0825

3.4.2 Obstacle factor diagnosis model

The evaluation results of the entropy weight TOPSIS method can reflect the level of sustainable development of grain family farms, but it is more important to determine the importance of each indicator. Therefore, we use the obstacle factor diagnosis model to scientifically rank the obstacle degree of the sustainable development of grain family farms to determine the importance of each indicator. The specific calculation formula is as follows:

$$O_j = \frac{I_j W_j}{\sum_{i=1}^{m} I_j W_j} \tag{12}$$

TABLE 5 Proximity degree of the sustainable development level.

Dimensions	Type	Hunan Province	Central Hunan	Northern Hunan	Southern Hunan	Western Hunan
Economic benefits	Rankings		1	2	3	4
	Proximity degree	0.380	0.407	0.396	0.370	0.348
	Judging rating	Good	Good	Good	Good	Good
Social benefits	Rankings		2	1	4	3
	Proximity degree	0.437	0.451	0.452	0.424	0.423
	Judging rating	Good	Good	Good	Good	Good
Ecological benefits	Rankings		4	2	1	3
	Proximity degree	0.371	0.330	0.361	0.429	0.363
	Judging rating	Good	Good	Good	Good	Good
Comprehensive benefits	Rankings		3	2	1	4
	Proximity degree	0.393	0.389	0.397	0.410	0.378
	Judging rating	Good	Good	Good	Good	Good

In Equation 12, O_j is the obstacle degree, and I_j is the index deviation degree, which can be expressed as the difference between the optimal target value and the actual value of the indicator.

4 Results

4.1 Index weight distribution

Stata 15 software was used to calculate the information entropy and corresponding weights of the 24 indicators. The results based on the entropy weight TOPSIS method are shown in Table 4 below. The number of farmer jobs provided (0.19), the intensity of soil protection and improvement (0.19), the effective use of water resources (0.16), and the intensity of social services and support (0.16) are the top four in terms of weight. The number of green production behaviors (0.05), the status of ecological development planning (0.08), income from agricultural tourism and rural experience (0.0847), and the grain planting area (0.09) are the last four.

4.2 Evaluation of the sustainable development level of grain family farms

Based on the entropy weight TOPSIS method, the proximity degree of the sustainable development level of grain family farms in Hunan Province, central Hunan, northern Hunan, southern Hunan and western Hunan was obtained (Table 5). The closer the proximity degree is to 1, the higher the sustainable development level is. From the perspective of comprehensive benefits, the proximity degree of Hunan Province is 0.393. According to Table 3, the overall sustainable development level is classified as good, which is worse than the results in the existing literature. Compared with previous research, we consider more social benefits and ecological benefits, and less economic benefits. Therefore, social benefits and ecological benefits are given more weight, but their ratio is smaller, so the overall level of sustainable development of grain family farms obtained by the comprehensive calculation in Hunan Province is smaller.

However, we need to explore the sustainable development level of grain family farms in four regions of Hunan Province. Therefore, we present the sustainable development level of grain family farms in four regions of Hunan Province (Table 6).

The following contents describe the results at each of the four regions.

Firstly, the sustainable development level of grain family farms in central Hunan. Central Hunan includes Changsha, Zhuzhou, Xiangtan, Loudi, and Shaoyang. In terms of comprehensive benefits, the proximity degree of central Hunan is 0.389, ranking third, and the comprehensive benefit performance is not good. However, from the perspective of economic benefits, central Hunan performs better, ranking first with a proximity degree of 0.407. In terms of social benefits, central Hunan performs well, ranking second with a proximity degree of 0.451. However, from the perspective of ecological benefits, the proximity degree of central Hunan is 0.330, ranking last. The findings here are consistent with those in the existing literature. Please see Section 5.1 of this article for reasons.

Secondly, the sustainable development level of grain family farms in northern Hunan. Northern Hunan region includes Yueyang, Yiyang, and Changde. In terms of comprehensive benefits, the proximity degree of northern Hunan is 0.397, ranking second. From the perspective of economic and ecological benefits, the proximity degree of northern Hunan is 0.396 and 0.361, respectively, ranking second, while from the perspective of social benefits, the proximity degree of northern Hunan is 0.452, ranking first. The findings here are consistent with those in the existing literature. Please see Section 5.1 of this article for reasons.

Thirdly, the sustainable development level of grain family farms in southern Hunan. Southern Hunan region includes the cities of Chenzhou, Yongzhou and Hengyang. In terms of comprehensive

TABLE 6 The sustainable development level of grain family farms in four regions.

Region	City	Dimension							
		Economic benefit		Social benefit		Ecological benefit		Comprehensive benefit	
		Proximity degree	Ranking	Proximity degree	Ranking	Proximity degree	Ranking	Proximity degree	Ranking
Central Hunan	Changsha, Zhuzhou, Xiangtan, Loudi, and Shaoyang	0.407	1	0.451	2	0.330	4	0.389	3
Northern Hunan	Yueyang, Yiyang, and Changde	0.396	2	0.452	1	0.361	2	0.397	2
Southern Hunan	Chenzhou, Yongzhou, and Hengyang	0.370	3	0.424	4	0.429	1	0.410	1
Western Hunan	Xiangxi Tujiazu and Miaozu Autonomous Prefecture, Huaihua, and Zhangjiajie	0.348	4	0.423	3	0.363	3	0.378	4

benefits, the proximity degree of southern Hunan is 0.410, ranking first. From the perspective of ecological benefits, the proximity degree of southern Hunan is 0.429, ranking first. From the perspective of economic benefits, the proximity degree of southern Hunan is 0.370, ranking third. From the perspective of social benefits, the proximity degree of southern Hunan is 0.424, ranking last. The findings here are consistent with those in the existing literature. Please see Section 5.1 of this article for reasons.

Finally, the sustainable development level of grain family farms in western Hunan. Western Hunan region includes Xiangxi Tujiazu and Miaozu Autonomous Prefecture, Huaihua, and Zhangjiajie. In terms of comprehensive benefits, the proximity degree of the Xiangxi region is 0.378, ranking fourth. From the perspective of social and ecological benefits, the proximity degree of western Hunan is 0.423 and 0.363, respectively, ranking third, while from the perspective of economic benefits, the proximity degree of western Hunan is 0.348, ranking last. The findings here are consistent with those in the existing literature. Please see Section 5.1 of this article for reasons.

4.3 Diagnosis and analysis of the obstacle degree

To further analyze the obstacle factors and their differences in terms of the sustainable development level of grain family farms, we carry out an obstacle degree diagnosis analysis of the index layer and ranks the top six indicator obstacle factors according to the obstacle degree (Table 7).

The common obstacle factors that rank among the top six factors affecting the sustainable development level of grain family farms are mainly concentrated in the criterion layer of ecological benefits and economic benefits. The criterion layer of ecological benefits includes four common obstacle factors: the effective use of water resources (C_{20}), the intensity of soil protection and improvement (C_{21}), the frequency of agricultural ecological culture inheritance activities (C_{22}), and carbon emission management (C_{23}). The criterion layer of economic benefits includes two common obstacle factors: the number of farmer jobs provided (C_2) and the ability to adapt to external environmental changes (C_7). Additionally, the common obstacle factors were the intensity of social services and support (C_{11}) (the criterion layer of social benefits), mainly in southern Hunan and western Hunan. Compared with the research conclusions in the existing literature, the conclusion here shows that the common obstacle factors are concentrated in not only the criterion layer of economic benefits, but also the criterion layer of ecological benefits and social benefits. In addition, the common obstacle factors of the criterion layer of ecological benefits are more than those of the criterion layer of economic benefits. The possible reasons mainly include the following two points. Firstly, compared with the existing literature, we set up more indicators of ecological benefits and social benefits and strengthened the monitoring of the pro-environment and social responsibility performance behavior of grain family farms. Secondly, grain family farms may abdicate social responsibility and carry out production behaviors that destroy the ecological environment in order to pursue short-term economic interests. The

TABLE 7 Obstacle factors and the obstacle degree of the sustainable development level.

Region	Type	Index ranking					
		1	2	3	4	5	6
Hunan Province	Obstacle degree	8.612%	8.540%	7.573%	7.253%	5.963%	5.853%
	Obstacle factors	C_2	C_{21}	C_{23}	C_7	C_{22}	C_{20}
Central Hunan	Obstacle degree	8.988%	7.190%	6.997%	6.453%	6.353%	6.275%
	Obstacle factors	C_{21}	C_7	C_{20}	C_{22}	C_2	C_{23}
Northern Hunan	Obstacle degree	8.778%	7.680%	7.529%	7.462%	6.570%	5.760%
	Obstacle factors	C_{21}	C_{23}	C_7	C_2	C_{22}	C_{20}
Southern Hunan	Obstacle degree	10.655%	8.590%	7.676%	7.279%	5.672%	5.647%
	Obstacle factors	C_2	C_{23}	C_7	C_{21}	C_{22}	C_{11}
Western Hunan	Obstacle degree	9.978%	9.117%	7.747%	6.615%	5.789%	5.204%
	Obstacle factors	C_2	C_{21}	C_{23}	C_7	C_{11}	C_{20}

reason analysis for each common obstacle factor is provided in Section 5.2.

5 Discussion

5.1 Analysis of reasons for the sustainable development of grain family farms in four regions

In terms of central Hunan, it is the economic center of Hunan Province. According to the research on the relevant literature mentioned above, its GDP in the first half of 2024 accounted for 51.68% of the whole Hunan Province (Ji and Zeng, 2020; Tang, 2021). However, it may have been over-pursuing economic development for a long time while ignoring the protection and management of the agricultural ecological environment and neglecting the value-added construction of agricultural ecological economy (Effland, 2022; Lacy et al., 2023), resulting in the lowest ecological benefit ranking. There may be some problems in central Hunan, including industrial pollution, the over-development of land resources and the destruction of the agroecological system, which not only cause direct damage to the local agroecological environment but also negatively impact people's life quality and health and may even cause long-term economic losses. This has a great negative impact on the economy, society and ecology (Liu, 2024; Zhang et al., 2024). Therefore, the development of the agricultural economy and the protection of the agroecological environment should complement each other. Only through reasonable planning and management can the sustainable development of the economy, society and ecology be realized.

In terms of Northern Hunan, on the one hand, it may have made remarkable progress in agricultural social governance and public services such as the social security system and community management mechanism, which provides a strong auxiliary support for the social development (Li et al., 2017; Dai, 2022), thus driving the improvement in social benefits. On the other hand, by guiding the optimization and up-grading of the agricultural industrial structure and increasing the intensity of scientific and technological innovation, it may have made certain achievements in the adjustment, transformation and upgrading of the agricultural economic structure, promoted the sustainable development of the agricultural economy to some extent, and laid a solid economic foundation for the improvement in social benefits, which promotes the harmonization of economic and social benefits (Li, 2022; Zhao et al., 2022). In addition, northern Hunan may pay attention to the protection and restoration of the agricultural ecological environment. It may improve the quality of the local agricultural ecological environment and provide a liveable living environment by strengthening the management of the agricultural environment and promoting the construction of an agricultural ecological civilization and other measures, thus promoting the improvement in social benefits, which promotes the harmonization of ecological and social benefits (Kahindo and Blancard, 2022; Lucas and Gasselin, 2022).

In terms of southern Hunan, Firstly, it may pay more attention to the construction of an ecological civilization and may take effective measures, such as strengthening agricultural environmental management and promoting agricultural ecological protection projects, to ensure the stability and improvement in the local agricultural ecological environment, and it has achieved remarkable results in the protection and restoration of the agricultural ecological environment, receiving the highest ecological benefit ranking (Kurisu, 2023; Tanaka et al., 2023). Second, in terms of economic development and social progress, there may still be realistic challenges and deficiencies in southern Hunan, such as the relatively single economic structure, the insufficient diversification of agricultural industry development, and the low level of agricultural social governance and public services, which limit the comprehensive performance of agricultural economic and social benefits in southern Hunan, resulting in relatively poor economic and social benefits (Li and Cai, 2022; Zhao et al., 2022). This situation is in sharp contrast to its excellent performance in agricultural ecology. This seems to contradict ecological benefits with economic benefit and social benefit. In other words, while paying attention to ecology, it may damage certain economic benefit and social benefit, but in the long run, the good development of ecology will be compatible with and coordinated with economic and social development, and will certainly promote the sustainable development of economy and society, bringing good economic and social benefits to achieve the coordinated development of the three (Ji and Zeng, 2020; Tang, 2021). Therefore, ecology, economy and society are a community, and they ultimately can be promoted together.

In terms of western Hunan, On the one hand, the picturesque scenery and beautiful ecological environment in western Hunan attract a large number of tourists, promote the prosperity of local tourism, provide rich employment opportunities for local residents, and thus improve the life quality and social stability of residents, obtaining some economic benefits and social benefits (Fan, 2016; Yang and Zhuang, 2022). In addition, the profound cultural heritage of Tujiazu, Miaozu in western Hunan makes it uniquely attractive in terms of cultural tourism and folk performance, which injects new vitality into the economic development of western Hunan, helping improve economic benefits (Liu et al., 2020; Li and Xu, 2021). On the other hand, compared with other regions, western Hunan has a single economic structure, weak scientific and technological innovation, and lagging agricultural industry development, and it is limited by its geographical environment and traffic conditions. Additionally, the degree of agricultural modernization and the industrial chain are relatively weak. This situation leads to a relative deficiency of economic benefits and restricts the sustainable and healthy development of the economy, resulting in the bottom of the comprehensive benefits (Fan, 2016; Yang and Zhuang, 2022).

5.2 Analysis of reasons for the common obstacle factors

In terms of the common obstacle factors of the criterion layer of ecological benefits and economic benefits, the finding indicates that grain family farms are facing great challenges in terms of ecological environmental protection, and it also highlights their inadequacy in terms of economic operation. This situation may be due to the following reasons. First, the ecological environment is damaged in the production and operation process of farms, and the excessive use of resources leads to the deterioration of ecological elements such as water resources and soil, which in turn limits the production capacity of farms, leading to poor performance of economic benefit, social benefit and ecological benefit (Md Hamdan et al., 2024; Shen et al., 2024). Second, factors such as the insufficient inheritance of agricultural ecological culture and inadequate management of carbon emissions reflect the lack of ecological awareness and poor management level of farms, leading to the depletion of the ecological environment and a weakening of the self-regulation capacity of agro-ecosystems (Fan et al., 2023; Seremesic et al., 2024). At the same time, problems related to economic benefits may be related to the farm management system, the market mechanism, policy support and other factors, which require the joint efforts of the government, enterprises and farm operators to achieve the improvement of economic benefits (Dona et al., 2024; Sambuichi et al., 2024).

In terms of the common obstacle factors of the criterion layer of social benefits, the finding reflects that the intensity of social services and support is one of the important factors for ensuring the sustainable development of grain family farms. The reasons may be that, first, there may be problems such as delayed agricultural infrastructure construction and inconvenient transportation in western Hunan and southern Hunan, making it difficult for the government and other social institutions and farms to deliver services and support to farmers, preventing the realization of good social benefits (Reid-Musson et al., 2022; Azima and Mundler, 2023). Second, there may be problems such as an inadequate implementation of agricultural policies, insufficient investment in agricultural funds, and a lack of agriculture-related human resources, which limit the provision of services and support, hindering the promotion of social benefits (Smedzik-Ambrozy et al., 2021; Bojnec et al., 2022). Third, there may also be information asymmetry and a low level of awareness among farmers, resulting in farmers' weak awareness of the need for external services and support, which in turn affects the provision of services and support and then hinders good social benefits (Saggin et al., 2018; Silva Júnior and Pedlowski, 2022).

6 Conclusion

We construct an index system for the sustainable development level of grain family farms, and uses this index system to compare and analyze 400 grain family farms and diagnose the obstacle degree. The following conclusions are drawn: (1) From the perspective of the proximity degree, the sustainable development level of grain family farms in Hunan Province is classified as good overall, but there are comparative differences in each dimension among the four regions. (2) According to the diagnosis and analysis results of the obstacle degree, the top six obstacle factors affecting the sustainable development level of grain family farms in Hunan Province are the effective use of water resources, the intensity of soil protection and improvement, the number of agricultural ecological culture inheritance activities, carbon emission management, the number of farmer jobs provided, and the ability to adapt to external environmental changes. There are regional differences in the ranking order of each obstacle factor. From the analysis of the results, the suggestions are as follows.

6.1 Government actions

First, the government should increase its support for the agricultural scientific and technological innovation of farms, encourage farmers to adopt advanced planting technology and management modes, and improve the efficiency and quality of agricultural production. Second, infrastructure construction should be strengthened, the levels of rural transportation, water conservancy, power supply and other infrastructure should be improved, and farm production and living conditions should be enhanced. At the same time, the government should also strengthen the training and skills upgrading of farm operators, improve their agricultural production and operation management levels, and enhance their ability to adapt to market competition. Third, the government should formulate a sound policy system, create a good market environment, provide more market information and support services for farms, and promote the development of marketization and the branding of agricultural products. Finally, the quality and safety of farm agricultural products should be strengthened, the rights and interests of consumers should be protected, and the competitiveness and market reputation of farm agricultural products should be enhanced. In addition, the government should strengthen the protection and management of the agricultural ecological environment to promote the sustainable development of farms, which ensures Chinese food security and gives full play to the important role of farms in the process of Chinese agricultural and rural modernization (Duan and Pan, 2024).

6.2 Environmental protection and modernization

First of all, in central Hunan, we should strengthen the protection and restoration of the ecological environment, promote the transformation of farm production to eco-friendly methods, and encourage farmers to adopt agricultural models of environmental protection such as water-saving irrigation and organic agriculture to improve the ecological benefits of farms. Secondly, in northern Hunan, we should pay attention to the development of agricultural social public welfare undertakings, increase the income level of farms and farmers, and strengthen infrastructure construction and the social service supply to improve the life quality of rural residents and the social environment of farm production. In southern Hunan, it is necessary to promote the adjustment of the agricultural industrial structure, promote the development of agricultural modernization, increase investment in farm agricultural science and technology, improve farm production efficiency, and strengthen farmer education and medical security to improve social benefits. Finally, in western Hunan, we should increase the support of farm funds and resources, encourage farms to carry out diversified operations and industry development, develop value-added services such as characteristic agricultural products and rural tourism, enhance agricultural value added, and strengthen ecological protection and land management to achieve the coordinated development of economic, social and ecological benefits.

6.3 Large scale and dimensional transverse actions

There are commonalities in the obstacle factors of grain family farms in different regions. First, we should strengthen the protection and utilization of farm water resources, promote water-saving irrigation technology, improve water resource management systems, and ensure the rational use of water resources. Second, we should strengthen the protection of farm soil, implement soil protection policies, promote the use of organic fertilizers and biological fertilizers, and improve soil quality and crop yield. At the same time, we should strengthen agricultural ecological culture inheritance activities of farms, carry out farming culture and rural tourism activities, and enhance the environmental protection awareness and ecological cultural literacy of farm operators and farmers. In addition, the government should strengthen the management of farm carbon emissions, formulate carbon emission reduction plans, and promote the development of farm production so that it is low carbon and environmentally friendly. At the same time, the government should increase support for rural employment and improve the quantity and quality of rural jobs. Finally, the monitoring and early warning of changes in the external environment of farms should be strengthened, counter-measures should be formulated, and the adaptability of farms to changes in the external environment should be improved.

Data availability statement

The raw data supporting the conclusions of this article will be made available by the authors, without undue reservation.

Ethics statement

Ethical review and approval was not required for the study on human participants in accordance with the local legislation and institutional requirements. Written informed consent from the (patients/participants OR patients/participants legal guardian/next of kin) was not required to participate in this study in accordance with the national legislation and the institutional requirements.

Author contributions

WD: Conceptualization, Data curation, Investigation, Methodology, Software, Validation, Visualization, Writing – original draft. YP: Investigation, Resources, Supervision, Writing – review & editing.

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Conflict of interest

The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

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References

Azima, S., and Mundler, P. (2023). Farmer satisfaction and short food supply chains. *Agric. Hum. Values* 40, 1531–1536. doi: 10.1007/s10460-023-10447-1

Bayrakdaroglu, A., and Yalçin, N. (2013). A fuzzy multi-criteria evaluation of the operational risk factors for the state-owned and privately-owned commercial banks in Turkey. *Hum. Ecol. Risk Assess.* 19, 443–461. doi: 10.1080/10807039.2013.755098

Biswas, S. S., Ahad, M. A., Nafis, M. T., Alam, M. A., and Biswas, R. (2021). Introducing "α-Sustainable Development" for transforming our world: a proposal for the 2030 agenda. *J. Clean. Prod.* 321:129030. doi: 10.1016/j.jclepro.2021.129030

Bojnec, S., Ferto, I., and Podruzsik, S. (2022). What drives family farm size growth in Hungary? *Heliyon* 8:e11890. doi: 10.1016/j.heliyon.2022.e11890

Boudedja, K., Ameur, F., Bouzid, A., and Belhadi, A. (2024). The spread of the intensive agricultural model by agro-suppliers in Algeria: implications for citrus small family farms and their adaptations. *Cahiers Agric.* 33:1–9. doi: 10.1051/cagri/2024010

Casagrande, D., Emanuel, L., Freitas, C., and Oliveira, F. (2024). Climate adaptation policies and rural income: evidence from social technologies in Brazil. *World Dev.* 181:106683. doi: 10.1016/j.worlddev.2024.106683

Dai, X. Q., Pu, L. J., Jiang, D. B., Zhang, Y., and Rao, F. P. (2024). Farmers' willingness to accept compensation for ginkgo conservation: evidence from rural Taixing, China. *Front. Sustain. Food Syst.* 8:1288405. doi: 10.3389/fsufs.2024.1288405

Dai, Z. G. (2022). Evaluation and regional difference of agricultural green production level in Liaoning Province. *Chin. J. Agric. Resour. Reg. Plann.* 43, 38–45. Available at: https://kns.cnki.net/kcms2/article/abstract?v=su5nt4ZpZVQRlPzm_Cykd7Wo_znZot0BbCMYsLJSRKmWH-j5jAwUGItm9tKrm5rhuFLExY1K-UuH-yncFqWN7Uhz_cFa8Q8sVUd6uiDVsQr_axVSTe8_-XSVeZ8druME2giN5E0aWCMkz3nst7k74DrPWaRHe8ChnWjS4WHcxR8HUYo25gt4PcC36NlZ6HcFYZQJ7u0Vmk6M3Bx6hoXYqXHdXBOJwIRE5cj2WDQf_Dc=&uniplatform=NZKPT&language=CHS

de Oliveira, L. G., Batalha, M. O., Oliveira, A. C., and Fonseca, V. S. (2024). National School Feeding Program (PNAE): a conceptual model of barriers to acquiring family farming food items. *Cienc. Rural* 54, 1–10. doi: 10.1590/0103-8478cr20220329

Deng, F. M., Liu, C. M., and Liang, X. D. (2017). Measurement of regional agricultural sustainable development system based on dissipative structure theory: a case study in Sichuan Province, China. *Sustainability* 9:2047. doi: 10.3390/su9112047

Dona, C.G. W., Mohan, G., and Fukushi, K. (2024). Multifunctionality benefits of small-scale urban agriculture. *Sustain. Sci.* 19, 967–987. doi: 10.1007/s11625-023-01447-5

Du, X. (2024). A comparative analysis of the productivity of small farmers and family farms in China: an empirical study based on the comprehensive survey data of rural revitalization in China. *J. Beij. Norm. Univ.* 1, 30–41. Available at: https://kns.cnki.net/kcms2/article/abstract?v=su5nt4ZpZVRQNc75U_cOZh7mPg3z9dcdbduzm4ISrWS_2QRV75hW8VgULr1fmsjorXRr_F7lajAP6QW1TXhwrqF9DWP_ntZLBw9D6b-SDuVjMwkxumJ79edRl9bw2E3kbxBTknQQeV5rFEoYuZElGQ5PnEmwfQrMdiUqqZm7zAp_Qws55AI_LJHiVDTSeuue&uniplatform=NZKPT&language=CHS

Duan, W., and Pan, Y. H. (2024). Driving logic and practical exploration of high-quality agricultural development in China in the new era. *Agric. Outlook* 20, 13–17. Available at: https://kns.cnki.net/kcms2/article/abstract?v=su5nt4ZpZVTHaygRanBnAVyRAvuIKI3E1LUPtKyAulW16CqSu6rSVfMjWAj0R-QOIVHzD4c4IXVXUkihYywiL21Z1o2jdgdQwE-U8ZyY85xYDuNQ5NkKzIGnxKLVWQSuvpTVyzMQw56U6teotty5y_CufqlejO5ws__Hfg9TYfJeaSIAjDClOLnh7I6TQio0VT7UklsbGQfH06m_gOJGrjKqFaEOvFrvGN0wzu_ruMCGjLiNvB5qhr-FYGK-MWBLe84X94A__cU=&uniplatform=NZKPT&language=CHS

Effland, A. (2022). American agriculture: from farm families to agribusiness. *Agric. Hist.* 96, 650–652. doi: 10.1215/00021482-100100011

Fan, H. C. (2016). Thinking on the countermeasures of implementing the appropriate scale land management in the west hilly area. *J. Southwest Minzu Univ.* 37, 156–161. Available at: https://kns.cnki.net/kcms2/article/abstract?v=su5nt4ZpZVRkA8cIKs4snw3wXi_TvzZLdnOMgimUfw2YQQccZc-f6bRwFdjI_KftQSex2Cv0WjGammwmgDm5LM6fRqYRrlvAOOQCJa89uvPxs-kapIqh1q5AQWhOUfIrCcIwieTTMsuottekA2FxeknTpneQlE_7DavWXh1Nmng=&uniplatform=NZKPT

Fan, J. P., Wang, Q., Ji, M., Sun, Y. J., Feng, Y. G., Yang, F. S., et al. (2023). Ecological network construction and gradient zoning optimization strategy in urban-rural fringe: a case study of Licheng District, Jinan City, China. *Ecol. Indic.* 150:110251. doi: 10.1016/j.ecolind.2023.110251

Farley, J., and Schmitt, A. (2024). Building a restorative agricultural economy: insights from a case study in Santa Catarina, Brazil. *Sustainability* 16:4788. doi: 10.3390/su16114788

Ferrari, A., Bacco, M., Gaber, K., Jedlitschka, A., Hess, S., Kaipainen, J., et al. (2022). Drivers, barriers and impacts of digitalisation in rural areas from the viewpoint of experts. *Inf. Softw. Technol.* 145:106816. doi: 10.1016/j.infsof.2021.106816

Fu, W. L. H., and Li, Z. J. (2024). Credit rating of family farms based on optimal assignment of credit indicators by BP neural network. *Agric. Finan. Rev*. 84, 175–190. doi: 10.1108/AFR-02-2024-0026

Gai, M., Gai, Y., and Zhang, Y. L. (2014). Index system and evaluation of urban sustainable development level. *J. Liaoning Norm. Univ.* 1, 91–94. Available at: https://kns.cnki.net/kcms2/article/abstract?v=su5nt4ZpZVS1bXEmPc3j5R6bpbRMFhrD047WK8xojhviRRTc-eFHrGlKR66VZRrv9C-X9YE0xMA4x2M_s7jdQ1Mv6UWCxsBRiCDKdAfTAO2EbjS1o8Ahq10Uky1OezIS98xKnz4nBQEOeTFp0k9DjnVSh00BppoQ&uniplatform=NZKPT

Ge, J. G., and Li, L. M. (2023). Dual innovation of the business model: the regulatory role of entrepreneurial orientation in family firms. *J. Bus. Ind. Market.* 38, 1587–1599. doi: 10.1108/JBIM-03-2022-0157

Guevara-Hernández, F., Arias-Yero, I., La O-Arias, M. A., Fonseca-Flores, M., and Pinto-Ruiz, R. (2024). Sustainability of native maize family farms in Mexico: current trends from a socio-agronomic perspective. *Emir. J. Food Agric.* 36, 11–14. doi: 10.3897/ejfa.2024.118595

Guzman, P. (2020). Assessing the sustainable development of the historic urban landscape through local indicators. Lessons from a Mexican World Heritage City. *J. Cult. Herit.* 46, 320–327. doi: 10.1016/j.culher.2020.06.017

Hao, S. L., Ren, C. B., and Zhang, L. (2022). Research on performance evaluation of coal enterprises based on grounded theory, entropy method and cloud model from the perspective of ESG. *Sustainability* 14:1526. doi: 10.3390/su141811526

He, G. S., and Li, D. (2012). Measurement and comparison of sustainable development of China's listed commercial banks. *J. Northeast. Univ.* 14, 23–28+41. doi: 10.15936/j.cnki.1008-3758.2012.01.012

He, Z. T., and Wang, S. (2023). Study on the appropriate scales of breeding-type family farms from the perspective of quantifying resource losses. *J. Air Waste Manage. Assoc.* 73, 578–588. doi: 10.1080/10962247.2023.2208092

Ji, G., and Zeng, F. S. (2020). Structural reform of grain supply side based on the perspective of production factors. *J. Soc. Sci. Hunan Norm. Univ.* 49, 82–86. doi: 10.19503/j.cnki.1000-2529.2020.02.011

Kahindo, S., and Blancard, S. (2022). Reducing pesticide use through optimal reallocation at different spatial scales: the case of French arable farming. *Agric. Econ.* 53, 648–666. doi: 10.1111/agec.12703

Karahalios, H. (2020). A risk assessment of ships groundings in rivers: the case of Parana River. *J. Navigat.* 73, 833–845. doi: 10.1017/S0373463319000936

Kostov, P., Davidova, S., and Bailey, A. (2018). Effect of family labour on output of farms in selected EU Member States: a non-parametric quantile regression approach. *Eur. Rev. Agric. Econ.* 45, 367–395. doi: 10.1093/erae/jbx036

Kumar, K. R., Damab, K. K., and Venkatasatyanarayana, V. (2024). Application of Taguchi based entropy weighted TOPSIS method for AZ 91D magnesium alloy friction stir welded joints with cerium addition at interface. *J. Ceram. Process. Res.* 25, 151–158. Available at: https://webvpn.hunau.edu.cn/https/77726476706e69737468656265737421e7e056d22c33611e7907c7a78a/kciportal/ci/sereArticleSearch/ciSereArtiView.kci?sereArticleSearchBean.artiId=ART003074304

Kurisu, K. (2023). The Japanese preference for collaborations between citizen's farms and food-support organizations. *Ann. Nutr. Metab.* 79, 224–224. Available at: https://karger.com/anm/issue/79/Suppl.%201

Kurlavicius, A., Zukovskis, J., Gozdowski, D., and Wójcik-Gront, E. (2024). Economic, social, and environmental factors impacting resilience and disturbances of lithuanian family farms. *Agriculture* 14:1988. doi: 10.3390/agriculture14071088

Lacy, K., Orazem, P. F., and Schneekloth, S. (2023). Measuring the American farm size distribution. *Am. J. Agric. Econ.* 105, 219–242. doi: 10.1111/ajae.12318

Lee, C. C., and He, Z.W. (2024). The impact of green finance policy on land ecological security: city-level evidence from China. *Sustain. Cities Soc.* 105:105347. doi: 10.1016/j.scs.2024.105347

Li, H., Li, Y. Z., and Zhang, S. (2017). Research on evaluation of development level of ecological agriculture. *J. Harb. Univ. Commer.* 3, 88–97. Available at: https://kns.cnki.net/kcms2/article/abstract?v=su5nt4ZpZVSog8w-dM91NvTMEsKYK7FeUYGO4_1wocUt-L6_TD8wA-2ulFk08XXC_ImsNMEJ4k6LBFNcvVN2KpMBQ7dThStbOaInlr2zguSBRAKvvysvL6NrKm7UtPiAEkuuD5g45OvYztNR-eztdozKkPvLU2MVpWofW19P7Sg=&uniplatform=NZKPT

Li, J. L., Hu, H., and Jia, D. S. (2015). Construction and empirical study of sustainable development index of Marine economy: a case study of Shanghai. *Mar. Environ. Sci.* 34, 942–948. doi: 10.13634/j.cnki.mes.2015.06.023

Li, L. N. (2023). The concept of agricultural sustainable development and its sustainability accounting practice. *Chin. J. Agric. Resour. Reg. Plann.* 44, 41+51. Available at: https://kns.cnki.net/kcms2/article/abstract?v=su5nt4ZpZVTjYg0m4YkBothfP_wc1s55KPtYHYSTocPMCrS1HfaRYWL8AF5D__xuOfMtRVKh15jWAOPZz1y_2CFNaDywQwlanJYJAmKu24q6JsaRAGasK-TUET1VlH7owYwF-7EQUxJx3dgiskNntWMjumEbQxNSZ9U33OtCFsE=&uniplatform=NZKPT

Li, W. M., and Cai, Z. Y. (2022). Spatiotemporal differences and influencing factors of high-quality utilization of land resources in the Yellow River Basin of China. *Environ. Sci. Pollut. Res.* 29, 89438–89448. doi: 10.1007/s11356-022-22077-x

Li, X. W., and Xu, S. B. (2021). Rural industry integration: horizontal measurement and spatial distribution pattern. *Chin. J. Agric. Resour. Reg. Plann.* 42, 60–74. Available at: https://kns.cnki.net/kcms2/article/abstract?v=su5nt4ZpZVSWetJ0EQkHYE6PRzzHdnBKn7mjv1auZArOmgKGC3DXNZvrQVFkH479us6ngIv7D-dMjYrSeuvjn8nM2STwPmncxVG8mTR6uQJvZNrXVyzF8Lu6F1hO2jFEMr3WVXsJ0C-LP39RjWGKog6-dswhxtu6LS8wBZQ0kh1wYLZyx-BIsZTEDj7qDlx_2YW6CxnaZd79d1cFifHOJdcfh5qQ0iKz4QSeHLYDQXXOrtyUI83gow==&uniplatform=NZKPT&language=CHS

Li, Y., Zhang, J. P., He, Y. Z., and Li, Z. (2023). Suitability evaluation method for preventive maintenance of asphalt pavement based on interval-entropy weight-TOPSIS. *Construct. Build. Mater.* 409:134098. doi: 10.1016/j.conbuildmat.2023.134098

Li, Y. A. (2022). The development scale of family farms and the transformation logic of "small farmers" and "large farmers". *Agric. Econ.* 11, 69–71. Available at: https://kns.cnki.net/kcms2/article/abstract?v=su5nt4ZpZVTOaZ4ydkepjAY07EOvSjH9m8mlOBSFsAqhDXRaqlK32c04jM5uB4ZZpU6R2lFnVVqzr2NpE-BS16obmLUHOJtDrZH4BfiWx5xqzWHf-4lG-dkZUPlIlD4oPOWCmfDAqi7mH5lzH4QwsroYx-M3WnIg_oOIgddmfvQ=&uniplatform=NZKPT

Li, Y. Y., Mao, X. H., and Huang, Z. H. (2023). Evaluation and countermeasures on the protection of quantity, quality and ecology of cultivated land under the background of national food security. *Rural Econ.* 6, 21–31. Available at: https://kns.cnki.net/kcms2/article/abstract?v=su5nt4ZpZVRATwDYv705dr-1kmnpmN3HQ7Ysj1IXlXBOXPcHZeTzJQyXbO2D9LJ6s-Duj2PwUMPJ-D9vvhi4af7enLbz0WOk3zseDc3pVAQzWEEZEae2RksS6XHdjLIeuSNZc-VaESQI-CRamUyr60WUFaOtupYwbuKAWbkXnAk=&uniplatform=NZKPT

Li, Z. D., Huang, C. Y., and Ma, Y. B. (2024). Regional differences and distribution dynamics of ecological environment measurement levels in the Yellow River Basin. *J. Henan Norm. Univ.* 51, 39–45. doi: 10.16366/j.cnki.1000-2359.2024.02.06

Li, Z. J., Wang, T. T., and Zhang, J. H. (2023). Dynamic credit evaluation and prediction of family farms and ranches based on optimal time weight Vector. *J. Nonlinear Convex Anal.* 24, 1341–1355. Available at: http://www.yokohamapublishers.jp/online2/jncav24-6.html

Li, Z. P., and Li, X. J. (2023). Evaluation of development level of rural revitalization and diagnosis of obstacle factors in Yangtze River Delta region. *Statist. Decis.* 39, 77–81. doi: 10.13546/j.cnki.tjyjc.2023.06.014

Lim, S., Lee, C. H., Bae, J. H., and Jeon, Y. H. (2024). Identifying the optimal valuation model for maritime data assets with the analytic hierarchy process (AHP). *Sustainability* 16:3284. doi: 10.3390/su16083284

Liu, L. H. (2024). The path to realize the moderate scale concentration of family farm land. *Seeker* 4, 151–160. doi: 10.16059/j.cnki.cn43-1008/c.2024.04.017

Liu, L. H., Tian, M. L., and Li, M. Y. (2020). Research on the impact of land transfer on economic benefits of family farms: based on a survey of 336 family farms in Sichuan, Hubei, Jiangsu and Shandong. *J. Hebei Univ. Econ. Bus.* 41, 87–97. doi: 10.14178/j.cnki.issn1007-2101.20200831.008

Liu, L. J. (2015). Empirical analysis of optimal allocation of rural regional market resources from the perspective of sustainable development. *J. Commerc. Econ.* 33, 53–54. Available at: https://kns.cnki.net/kcms2/article/abstract?v=su5nt4ZpZVTcMnZ4CJ9NJsHWJxP9muhShCOhQCh6ig5dxZY3o9j3ePoJtRqSILy_nqgbZr9rjHdqy5NnBdcVPxx_uPVPK9dFf8-b7s4OqylRnnrE9KRkgfejggS4XSl-jn_J1LKK0imVVvs8ZhyZ8C2m0UeMq-cqyo6OmQlgA4U=&uniplatform=NZKPT

Liu, X. M., and Zhang, T. M. (2021). Evaluation of agricultural modernization level in Hebei Province based on entropy weight TOPSIS. *Shand. Agric. Sci.* 53, 142–149. doi: 10.14083/j.issn.1001-4942.2021.07.023

Lucas, V., and Gasselin, P. (2022). An intensive and collective style of farm work that enables the agroecological transition: a case study of six French farm machinery cooperatives. *Front. Sustain. Food Syst.* 6:862779. doi: 10.3389/fsufs.2022.862779

Md Hamdan, L. H., Mohd Yusop, M. A., Naroh, A., Anak Tader Mojig, M. M., Anak Rady, R. A., Anak Phillip, A. S. M., et al. (2024). Fabrication of the mini multi-function pepper machine. *E3S Web Conf.* 479:1006. doi: 10.1051/e3sconf/202447901006

Namany, S., Govindan, R., Di Martino, M., Pistikopoulos, E. N., Linke, P., Avraamidou, S., et al. (2022). Developing intelligence in food security: an agent-based modelling approach of Qatar's food system interactions under socio-economic and environmental considerations. *Sustain. Prod. Consumpt.* 32, 669–689. doi: 10.1016/j.spc.2022.05.017

Newsome, L., Sheridan, A., Lawson, A., Charry, S., and Field, S. (2024). The "dreaded" daughter-in-law in Australian farm business succession. *J. Rural Stud.* 109:103324. doi: 10.1016/j.jrurstud.2024.103324

Niewiadomski, P., and Stachowiak, A. (2024). The sustainable production and well-being of employees as a derivative of the concept of sustainable production. *Sustainability* 16:465. doi: 10.3390/su16010465

Padda, I. U., and Hameed, A. (2018). Estimating multidimensional poverty levels in rural Pakistan: a contribution to sustainable development policies. *J. Clean. Prod.* 197, 435–442. doi: 10.1016/j.jclepro.2018.05.224

Peng, J. F., Liu, W., Liu, Y., and Mei, D. (2024). Evaluation of agricultural multifunction and diagnosis of obstacle factors in Chengdu-Chongqing area. *Chin. J. Agric. Resour. Reg. Plann.* 3, 1–15. Available at: http://kns.cnki.net/kcms/detail/11.3513.S.20240325.1319.014.html

Pérez-Piza, M. C., Vicente, S., Castellari, C. C., Mousegne, F., Jecke, F., Cornejo, P., et al. (2024). Timing is everything: how planting period shapes nutritional quality, mycobiota characteristics, and mycotoxin contamination in maize (*Zea mays*) grains. *Eur. J. Plant Pathol.* 169, 201–217. doi: 10.1007/s10658-024-02820-5

Reid-Musson, E., MacEachen, E., Beckie, M., and Hallström, L. (2022). Work without workers: legal geographies of family farm exclusions from labour laws in Alberta, Canada. *Agric. Human Values* 39, 1027–1038. doi: 10.1007/s10460-022-10302-9

Ren, Z., Li, X. D., Xue, X. L., and Li, C. X. (2015). Analysis of influencing factors of tobacco leaf family farm development – based on investigation of 542 tobacco leaf family farms in Weifang City, Shandong Province. *Acta Tabacaria Sinica* 21, 112–120. doi: 10.16472/j.chinatobacco.2014.357

Saggin, A. C., Gris, V. G. C., Rojo, C. A., and Brandalise, L. T. (2018). Production costs: a study on a family farm in Cafelandia/PR. *Custos Agron. Line* 14, 2–21. Available at: http://www.custoseagronegocioonline.com.br/numero4v14/OK%201%20familiar%20english.pdf

Sambuichi, R. H. R., Paula, S. D., Perin, G., de Almeida, A., Gualdani, C., and Marques, F. J. (2024). Public food procurement and food security: an assessment of the impacts of the PAA on family farming in Brazil. *Desenvolvimento Meio Ambiente* 63, 197–225. doi: 10.5380/dma.v63i0.91581

Sasongko, I., Gai, A. M., and Azzizi, V. T. (2024). Sustainable development concept of heritage *Kampung* tourism using novel prioritization approach. *Sustainability* 16:2934. doi: 10.3390/su16072934

Savickiene, J., and Miceikiene, A. (2018). Sustainable economic development assessment model for family farms. *Agric. Econ.* 64, 527–535. doi: 10.17221/310/2017-AGRICECON

Seremesic, S., Dolijanovic, Z., Simin, M. T., Seremesic, M. M., Vojnov, B., Brankov, T., et al. (2024). Articulating organic agriculture and sustainable development goals: Serbia case study. *Sustainability* 16:1842. doi: 10.3390/su16051842

Shen, S. S., Yan, D., and Liu, X. J. (2024). Achieving coordinated development of multi-functional urban agriculture in Xiamen, China. *Sustain. Cities Soc.* 101:105070. doi: 10.1016/j.scs.2023.105070

Shi, C. Y. (2023). Analysis and reflection on the experience of rural revitalization in France under the framework of multifunctional agricultural development. *Comp. Econ. Soc. Syst.* 44–54. Available at: https://kns.cnki.net/kcms2/article/abstract?v=su5nt4ZpZVTVD4UkMoO-QJDCCk_fEKOsYAcK5wDQ4EUDuwCXWEniVQtTMSRmnIKdPSCimRP8pxNaF2EdszzngAVJT8Yj_KT9Z9VUddmgywPyTvUtyoxVjOh9Dvnekigwikz3r1TG4EBsUv3fytm6UkoArj1h–j8XrH15xv35Yc=&uniplatform=NZKPT

Shi, L. Y., Han, L. W., Yang, F. M., and Gao, L. J. (2019). The evolution of sustainable development theory: types, goals, and research prospects. *Sustainability* 11:7158. doi: 10.3390/su11247158

Silva Júnior, J. L. P., and Pedlowski, M. A. (2022). Perception of family farmers on the socio-environmental impacts caused by Açu Port in São João da Barra, Rio de Janeiro, Brazil. *Soc. Nat.* 34:e63123. doi: 10.14393/sn-v34-2022-63123

Silva, J. A., Oliveira, T., Ribeiro, I., Fernandes, M. S. S., and Santos, G. (2023). Adequacy of school menus and national school food program requirements: a systematic review. *Rev. Bras. Saúde Materno Infantil* 23:e20220131. doi: 10.1590/1806-93042023000000131-en

Smedzik-Ambrozy, K., Guth, M., Majchrzak, A., Muntean, A. C., and Maican, S. S. (2021). The socio-economics factors in family farms with different economic sustainability levels from Central and Eastern Europe. *Sustainability* 13:8262. doi: 10.3390/su13158262

Tanaka, T. S. T., Mieno, T., Tanabe, R., Matsui, T., and Bullock, D. S. (2023). Toward an effective approach for on-farm experimentation: lessons learned from a case study of fertilizer application optimization in Japan. *Precis. Agric.* 24, 2044–2060. doi: 10.1007/s11119-023-10029-5

Tang, L. (2021). Tangjia Liangliang farm: integration of family and farm. *Open Times* 3, 2+225. Available at: https://kns.cnki.net/kcms2/article/abstract?
v=su5nt4Z pZVSF9uXnrG2BXSdN6CVE8IjdS50nXyBby4w41J974Cp6yBs_SEQIkiBx
dC_zhE36_4L5aP_wmz_FvMUFN9ztOBuQga_gpF_av_4OKIxY7VhL_8hLjNtWOfDH
LIZCerS3ZnTHKKBKgGtKxsaEwXRPRom-5n11FeVGhio=&uniplatform=NZKPT

Taysom, M. (2023). *Growing Pains: Amenity Migration and Farmer/Rancher Subjective Well-Being, a Case Study in Teton Valley*. Pocatello, ID: Idaho State University.

Tuliende, M., Martinelli, S. S., Soares, P., Fabri, R. K., Bianchini, V. U., and Cavalli, S. B. (2024). Benefits and difficulties of implementing family-farming food purchases in the Brazilian National School Feeding Program. *Int. J. Public Health* 69:1605870. doi: 10.3389/ijph.2024.1605870

Verger, E. O., and Le Bars, M. (2024). Achieving sustainability in family farming. *Curr. Res. Environ. Sustain.* 7:100235. doi: 10.1016/j.crsust.2023.100235

Wang, D. D., Wang, C., Chen, Y. L., and Xie, Z. H. (2023). Developing plant-growth-promoting rhizobacteria: a crucial approach for achieving sustainable agriculture. *Agronomy* 13:1835. doi: 10.3390/agronomy13071835

Wang, G. Y., Chen, Y. N., and Zhang, Z. Y. (2023). Ecological space evaluation under the framework of strong sustainable development. *China Popul. Resour. Environ.* 33, 30–43. Available at: https://kns.cnki.net/kcms2/article/abstract?v=su5nt4Z
pZVQCJeRGEgIQz6V7smH6awinOc_CI4OCyr7eoXzLNmkAVLRaWvjGYefGqqTqE
6K8UKUPMjpvoMNpEmfOYmwwwn-lPbkfLsYPdarc5WzAqtd8jZY6hyv_d4z
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rFJJ9WWJxGuV7Iznpq8sG8d9CgmZrA==&uniplatform=NZKPT&language=CHS

Wang, H., and Tang, Y. T. (2023). Spatiotemporal distribution and influencing factors of coupling coordination between digital village and green and high-quality agricultural development-evidence from China. *Sustainability* 15:8079. doi: 10.3390/su15108079

Wang, L., and Dong, M. (2023). An entropy weight-TOPSIS based method for e-commerce logistics service quality evaluation. *Tehn. Vjesnik Tech. Gazette* 30, 1253–1256. doi: 10.17559/TV-20230306000408

Wu, F. (2022). Adoption and income effects of new agricultural technology on family farms in China. *PLoS ONE* 17:e0267101. doi: 10.1371/journal.pone.0267101

Wuepper, D., Wimmer, S., and Sauer, J. (2021). Does family farming reduce rural unemployment? *Eur. Rev. Agric. Econ.* 48, 315–337. doi: 10.1093/erae/jbab002

Xiang, Z., Liu, X. Y., and Xiao, D. D. (2016). Preliminary evaluation and index application of energy sustainable development in China. *Shandong Soc. Sci.* 2, 168–173. doi: 10.14112/j.cnki.37-1053/c.2016.02.024

Xue, Y. J., Xue, Y. J., and Zhang, Y. Y. (2024). Does joining cooperatives enhance green total factor productivity of family farms? Evidence from 892 planting-oriented family farms in Jiangsu, Jiangxi, and Shaanxi Provinces of China. *Chin. Rural Econ.* 2, 67–89. doi: 10.20077/j.cnki.11-1262/f.2024.02.004

Yang, C. Y., and Zhuang, T. H. (2022). Study on the formation mechanism of family farm's pro-environment production behavior intention from a cognitive perspective—Micro empirical evidence from Sichuan. *Ref. Econ. Syst.* 4, 80–87. Available at: https://kns.cnki.net/kcms2/article/abstract?v=su5nt4Z
pZVRLm60CD4I6H7yoL_qS1BUz_i1i4dA3WXCEquo-3rFTR6PTwjorWXkrSqS_V
8UlwdKG690FAoOkFKr-Lc_v_UqKnbrdpNaTvub7wAkapOQzdvihcf87SJSlNmLEcl
2UIHkQMUbMvc2QRSDVo-JavGEwkae1lMbwlog=&uniplatform=NZKPT

Yuan, Z., Xu, F., Xie, Y. Q., and Li, Y. W. Z. (2023). The social innovation experience of multifunctional agriculture in Europe and its implications for China. *Urban Plann. Int.* 6, 1–16. doi: 10.19830/j.upi.2023.386

Zaharia, A., Diaconeasa, M. C., Brad, L., Ladaru, G. R., and Ioanas, C. (2019). Factors Influencing energy consumption in the context of sustainable development. *Sustainability* 11:4147. doi: 10.3390/su11154147

Zeng, J. W., Jing, G. X., and Zhu, Q. F. (2024). An emergency decision-making method for coal spontaneous combustion based on improved prospect theory. *Processes* 12:151. doi: 10.3390/pr12010151

Zhang, A. Z. (2023). Evaluation of the high quality development level of cultural industry in the Yellow River Basin. *Statist. Decis.* 39, 127–131. doi: 10.13546/j.cnki.tjyjc.2023.04.023

Zhang, J. J., Zhang, K. Y., Zhang, G. Q., Guo, L. X. (2024). Study on the choice of green production behavior and regional comparison of family farms. *Agric. Econ. Manag.* 1, 46–57. Available at: https://kns.cnki.net/kcms2/article/abstract?v=su5nt4Z
pZVQLe4Wu_qml1DG_rL71d3PbYsJsdQWFYBlAX_laPfB9cIFmI5u-BckjY5bKPn
600qT-aCeI20CFmX-hC6wy5_fVLLwBNC7dAsKpy3nQxXYo8KVkkli8Z4WHfUhC
iGh7MiCmpM6cWbFvx3Dc_VmVQ7go0fYQQELWTFY=&uniplatform=NZKPT

Zhang, R. T., and Chen, M. (2022). Spatial differentiation and driving mechanism of agricultural multifunctions in economically developed areas: a case study of Jiangsu Province, China. *Land* 11:1728. doi: 10.3390/land11101728

Zhang, R. T., and Chen, M. (2023). Spatial and temporal characteristics of Jiangsu agriculture multifunctional trade-offs and synergies based on county scale. *Chin. J. Agric. Resour. Reg. Plann.* 45, 222–232. Available at: https://kns.cnki.net/kcms2/article/abstract?v=su5nt4ZpZVQV4a96d4
OX2pvurBLpQUipbPM6jcn23AuBpCVrSxclDujAVs_QZv3nMZQqrqdTAQZCW9yix
fhFo6Wm0B1uzV9GOokfQzPUkv5VFbHefDS_RcQXyUhclKj1gV6kUvgk23Jyg-CN_
3-NqmDIy9WpTJOXlWhbdAPV4sGubBGfjXHLTtyzGYLrUF_AFgwndDp6-3Pg5mb
8zd8tk6mR2NlQmPZvNMFc-nXY1kH6TrYRDIZzfg==&uniplatform=NZKPT&lang
uage=CHS

Zhang, Z., and Zeng, G. (2021). Evaluation on sustainable development capability of regional innovative ecosystem in China. *J. Ind. Technol. Econ.* 40, 38–43. Available at: https://kns.cnki.net/kcms2/article/abstract?v=su5nt4Z
pZVRsf4lloFApyiESpS4YBmMM-Spw7RteRs_-SNBICXcI2N71jWb47GK5D7zI
GnyNL71WjG-eaA0vpFMC1YgR4m_aEVE2df3348KzVyU7TZUt-zwEJdHs0JELv06e
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27Ry0l2hyfc1tJt-QSuydGhui_VG9glLEVY&uniplatform=NZKPT&language=CHS

Zhao, Q. Y., Wan, C., Jiang, M., Zhang, Q., and Deng, M. X. (2022). Evaluation on the level of inclusive sustainable development in China's provinces. *Soc. Sci. Guangxi* 10, 134–145. Available at: https://kns.cnki.net/kcms2/article/abstract?v=su5nt4Z
pZVT728bX3im0Dg7XwhB2IDVjVWLMQFHZrlyR9GF3cMto9ZEsDI0qMLgBGQ-
D1SPXT-ON2PTZP2qignpGSDq50ONTMyEjmAfG6FIq4QW36ZPkCD5OLg3ko1v
j2rYSoWMZZXECIAEhhXOjVRRsE9lXCzu7t86LKRJZo70=&uniplatform=NZKPT

Zhu, W. L., Chen, J. H., Liang, X., Li, D. H., and Chen, K. (2024). Government regulations, benefit perceptions, and safe production behaviors of family farms – a survey based on Jiangxi Province, China. *J. Clean. Prod.* 450:141824. doi: 10.1016/j.jclepro.2024.141824