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REVIEW

Coordinating environmental protection and agricultural development: a village-based case study for promoting green transformation

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KEYWORDS

Agriculture green development, Science and Technology Backyards, Erhai, environmental protection, smallholders

HIGHLIGHTS

- Challenges of agricultural development in the Erhai Lake basin.
- STB model promoting agricultural green transformation in Erhai Lake basin.
- Approach and impact of the Erhai STB in agriculture green development.
- Balancing farmer income with environmental goals.
- Erhai's success: a blueprint for global sustainable farming.

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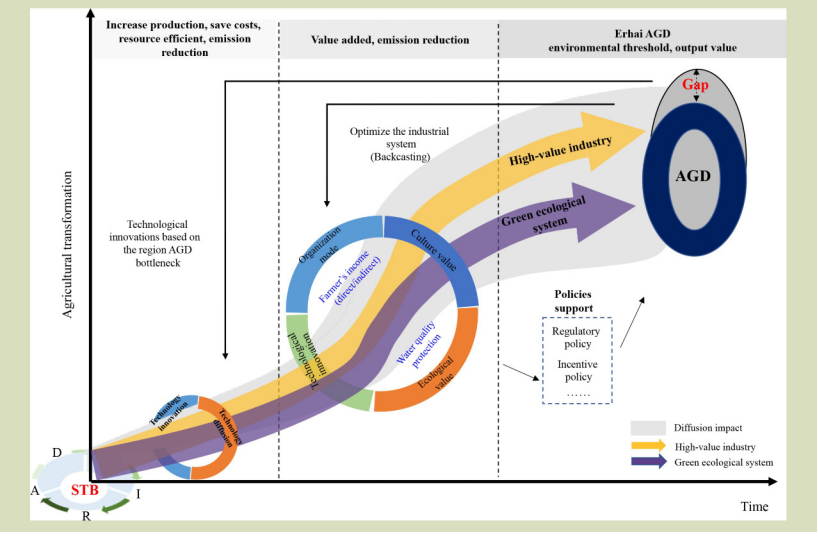
GRAPHICAL ABSTRACT



ABSTRACT

Balancing ecological preservation with sustainable agricultural practices is a global issue. Erhai Lake has felt this challenge keenly. To address it, in 2022, a Science and Technology Backyards (STBs) project was launched in Gusheng Village. The goal of this is to care for the environment while ensuring that farms and farmers can thrive sustainably. The uniqueness of the Erhai STB arises from its interdisciplinary integration, encompassing fields such as ecology, agronomy and social science, resulting in specifically-designed solutions for the Erhai context. While this model aligns with broader STB paradigms, its distinctive edge lies in technological innovation and robust support mechanisms for local agricultural stakeholders. This paper describes the methodology and outcomes of the STB initiative, highlighting its pivotal

role in spearheading sustainable transition in Erhai. Preliminary findings underscore the potential of the STB model as an efficacious tool for harmonizing environmental conservation and agricultural practices, that are both financially and environmentally sustainable, rendering it a potential model for comparable regions in China and other counties.

1 Challenges of agricultural development in the Erhai Lake basin

1.1 Protection and development dilemmas in Erhai

Erhai Lake, covering 252 km^2, located in Yunnan Province, is one of the seven largest freshwater lakes in China[1]. Erhai Lake is known as the Mother Lake of Dali City because it has had an important role in supporting the basic needs (e.g., drinking water) and economic development (e.g., tourism and irrigation for agriculture) of the residents in Dali City, which has a total population of 771,128[2]. However, over the last three decades, the lake has suffered pollution episodes, evidenced by three significant blue-green algae outbreaks in 1996, 2003 and 2013[3]. As of 2016, water quality levels were still below standard, and another severe algal bloom occurred in early 2017[4,5]. In response to this and other similar pollution challenges, the Chinese government, at both national and local levels, has implemented a comprehensive set of policies addressing water protection[6]. The updated land-use regulations have also restricted specific farming activities around lakes. Key measures involve strict restrictions on the use of mineral fertilizers and synthetic pesticides to minimize polluted agricultural runoff[7]. There is also an increased push toward organic farming, which not only avoids harmful chemical use but also enhances soil quality, decreasing erosion and subsequent runoff[8–10]. A crucial step has been the thorough treatment of agricultural wastewater before it mixes with the lake or its tributaries. Recently, the water quality has shown marked improvement due to these and other government interventions.

While these measures primarily aim to protect the environment, they have brought about significant socioeconomic impacts[11]. The tension between environmental preservation and economic stability has even been termed the Erhai dilemma[12]. In particular, the smallholders reliant on Erhai Lake grapple with the dual pressures of earning a living while adhering to environmental conservation mandates. These farmers rely on the lake as a shared resource, however, the collective tendency to overexploit the lake, even as some attempt conservation, has resulted in widespread overuse of the lake[13]. Evidently, the current state of agriculture in the Erhai basin presents considerable challenges for its future green development and transformation. The challenges in Erhai are representative of those of other lakes in Yunnan Province and, more broadly, throughout China.

This paper explores the efficacy of the Science and Technology Backyards (STBs) model as a potential solution to deal with the Erhai dilemma. STBs are a hub in a rural area that links knowledge with practices to promote technology innovation and exchange[14]. Acting as a nexus between scientific research and smallholder farming, STBs can foster sustainable farming practices, enhance community involvement and track behavioral shifts in farming practices[15,16]. The establishment of a STB in Erhai has created great potential for harmonizing environmental conservation with socioeconomic development, offering insights for broader applications both in China and globally.

1.2 The smallholder dilemma in Erhai

In the past, thousands of inns and restaurants were built around Erhai Lake to capitalize on its natural beauty. The sewage from these businesses was usually directly discharged into the lake[17]. In addition, a large amount of mineral fertilizer and synthetic pesticides applied to the surrounding farm land flowed into the lake as runoff, seriously degrading the lake water quality[18].

Since 2003, the Dali Municipal Government had taken stringent measures to combat pollution in and around Erhai Lake[19]. Initially, they revoked fishing tools (especially boats), restored over 8 km^2 of lakeside land to natural habitats, and imposed seasonal and zone-specific fishing bans affecting over 235 thousand locals[20]. Also, polluting factories were closed, investments threatening the environment were rejected and the sale of certain cleaning products was banned. Efforts also

included regulating fertilizer use, building wastewater pipelines and instituting centralized garbage collection systems[21]. To foster accountability, local officials signed pollution control commitments, with penalties for non-compliance. Public engagement was increased with cleanup campaigns, awareness advertisements and the introduction of environmental education for students, resulting in over 300 thousand students being educated in disciplines related to these issues[22].

In 2017, the Dali Municipal Government issued an announcement that regulated the tourism industry in the main commercial center of the Erhai Lake basin in order to improve environmental conditions[23]. All the inns and restaurants in the area were asked to suspend operations until they passed an inspection by the local environmental protection authority[19]. In total, 1900 establishments that were located along the lakeshore (or in close proximity to the lakeshore) were shuttered (1196 inns and 704 restaurants). As a consequence, tourism near Erhai Lake has been reduced to a trickle[19]. In 2019, the local government implemented stringent policies to protect Erhai Lake water quality. Among these, the policy of 'Three Bans and Four Promotions' had great impact on smallholder livelihoods[24]. The policy encompasses the following directives: a prohibition on the sale and use of fertilizers containing nitrogen and phosphorus, compounds of high-toxicity, high-residue pesticides; and a restriction on cultivating crops, primarily garlic, that demand excessive water and fertilizer. On the positive side, the policy advocates substitution of mineral fertilizers with organic ones, adopting eco-friendly pest control measures, pursuing green ecological cultivation of crops, and standardizing livestock and poultry breeding, alongside promoting ecologically sound aquaculture practices[24]. The introduction of the Erhai protection policy stands as another testament to the commitment of the Dali Municipal Government to environmental stewardship, aiming to halt and reverse the deteriorating water quality of the lake. However, this policy also reshapes the practices and prospects of the smallholders living in the region.

First, the policies have changed the environment on which smallholders make their decisions. The farming community around Erhai Lake has long maintained a nuanced equilibrium between crop and animal production practices. With limitations on agrochemical use, farmers were prompted to reconsider their primary crop selections, favoring those crops amenable to requiring fewer chemical interventions or organic cultivation[25]. This transition extended beyond merely adopting different crops; it entailed a fundamental transformation in farming methods, techniques and foundational knowledge[26]. As a result, many practices were adapted to meet the new standards, while others were phased out. For example, significant tracts of farmland and numerous livestock farms situated along the rivers leading into Erhai Lake were relocated out of the basin[19]. The cultivation practices suited to the unique geography and climate of the region, required for large-scale single-clove garlic cultivation, had to be reduced or even stopped. Land use in the Erhai Lake area[27] was instead repurposed for growing rice.

New policies had a pronounced impact on smallholder livelihoods[28]. For many, embracing organic farming or altered breeding methods entailed new investments, sometimes successful financial outlays and time commitments for training and knowledge assimilation[29]. Anticipating potentially reduced yields further strained financial capacity of farmers. Given this situation, smallholders confronted diverse immediate challenges to their livelihoods. While some dedicated themselves to mastering new agricultural techniques, others pursued sources of alternative income[30]. Against this backdrop, government subsidies and financial incentives became critical pillars of support for smallholders, alleviating their economic pressures[31]. These include subsidies for grain production, soil fertility improvements, agricultural product insurance and allowances for the purchase of farming tools. Such subsidies and financial incentives can be instrumental in reshaping farmer livelihoods. They not only offer immediate financial relief but also encourage more sustainable and advanced farming practices. However, this support also evoked discussions about long-term viability and dependency. Also, the measures designed for the preservation of Erhai have unintentionally disrupted the standard operations of the agricultural market, yielding notable consequences for smallholders. These disruptions can appear in various forms: reduced demand for specific crops, market access challenges or increased costs due to new environmental standards. Smallholders, often working with limited financial flexibility and lacking the means to quickly adapt, may bear the brunt of these changes. Without sufficient support or alternative options, their income is likely to declined significantly[30].

1.3 Pathways for implementing agriculture green development (AGD)

The basis of AGD is to coordinate environmental sustainability and economic development to realize the transformation of current agriculture with high resource consumption and high environmental costs into a green agriculture and countryside with high productivity, high resource use efficiency and low environmental impact[32]. This is a formidable task, requiring joint efforts of government, farmers, industry, educators and

researchers. The innovative concept for AGD will focus on reconstructing the whole crop-animal production and food production-consumption system, with the emphasis on high thresholds for environmental standards and food quality as well as enhanced human well-being[32].

AGD represents a critical need for the Erhai region in this contemporary age[33,34]. Firstly, it emphasizes coordinated goals, harmoniously achieving food security, efficient resource utilization, environmental protection, rural revitalization and green emissions reduction[35]. Secondly, interdisciplinary approaches are essential, as isolated academic fields cannot alone address comprehensive systemic challenges[32]. Thirdly, it stresses the need to capitalize on interface synergies, leveraging the potential of various interfaces to enhance their collective impact and improve system efficiency[36]. Fourthly, it requires collaboration across multiple entities rather than reliance on a single body. This calls for the integrated efforts of parties spanning governance, industry, academia, research and application[36]. Fifthly, multifaceted implementation strategies are crucial. From a top-down perspective, green checkpoints should be established and policy tools employed to optimize the entire agricultural system. From a bottom-up viewpoint, there is a need for innovative, applicable technologies and their implementation methods[37]. Lastly, holistic solutions covering the entire system are essential, linking green production, green products, green industry, green environment and green policies[38]. Exploring technological innovations and new application models focused on the green development of the entire system is of great importance, especially for regions confronted with severe agriculture-based environmental pollution problems as in Erhai.

The STB model emerges as a foundational tool in achieving these articulated goals, steering the trajectory toward AGD[14]. In 2009, China Agricultural University launched the STB initiative with the primary aim of empowering smallholders[39]. However, empowering these farmers was not the only goal of STBs. The broader vision encompassed aiding enterprises in leading industries, invigorating rural villages through rural revitalization strategies and facilitating a more extensive regional green transformation[14,40]. Currently, the STB approach promotes sustainable agricultural practices in many parts of China and has also been adopted in other countries. STBs serve as a crucial bridge, connecting advanced scientific research to everyday farming activities. This hands-on, community-oriented platform promotes proactive problem-solving, facilitated by a cohesive team of researchers, students, consultants and farmers. Also, STBs have become vital hubs for imparting science and technology knowledge in local communities. Through active engagement between STB specialists and influential farmers, science-driven management approaches are refined to suit practical farming contexts. By fostering immediate engagement between researchers and farmers, STBs accelerate the uptake of green farming innovations, augments local ecological cognizance, and catalyzes a shift toward sustainability-a trajectory also vital for the green transformation of Erhai agriculture[14,39].

2 STB model promoting agricultural green transformation in Erhai Lake basin

2.1 Evolution of the STB model

Over the past 15 years, leveraging the unique agricultural strengths encompassed within the region in which the STB settled down and three distinct service models of STBs have been conceptualized and deployed[14]: (1) STB 1.0: focused on one-to-one service to smallholders. Its primary goals were achieving high-yield and efficient agriculture, increasing income for farmers, and fostering a passion for agriculture among students to drive rural revitalization; (2) STB 2.0: emphasized collaboration with leading agricultural enterprises. The aim was to leverage these businesses to promote industry revitalization, thereby furthering rural resurgence; and (3) STB 3.0: aimed to nurture a new generation of farmers, cultivate new farmers, strengthen talent support for rural revitalization, enhance comprehensive rural governance, and advance both cultural and ecological restoration, thereby stimulating comprehensive rural advancement. It is crucial to understand that these models are not sequential but rather highlight different service emphases. In application, each STB model iteration maintains its dedication to supporting smallholders, engaging in corporate partnerships and promoting comprehensive village growth.

In the context of Erhai, the combined challenges of its agricultural and ecological setting demand an enhanced application of the STB model. Rather than merely introducing green technologies, the STB initiative in Erhai intertwines rigorous environmental conservation, the pursuit of sustainable farmer livelihoods and precision in introducing green technological measures. Such a context presents both unique challenges and opportunities. Given the strict environmental protection requirements of the region, every STB-driven technological intervention in Erhai needs to exhibit both innovation and precision at levels surpassing those in

other areas[41]. For example, nutrient management, a central component of sustainable agriculture, calls for increased controls and precision, ensuring ecological equilibrium.

The distinctiveness of the Erhai STB approach stems from its interdisciplinary core. Collaboration across diverse fields, from ecology, agronomy to social science, is not merely beneficial but essential. Such comprehensive interdisciplinary engagement yields holistic solutions tailored to the intricacies of the Erhai environment. Nonetheless, the core principles of the Erhai STB align with the general ethos of the STB model practiced elsewhere, emphasizing technological innovation and providing customized support to primary stakeholders, especially smallholders and businesses[42]. By steadfastly aiding these stakeholders, this STB aspires to elevate their technological competencies, translating theoretical innovations into tangible, ground-level applications[14]. The ongoing cycle of technological monitoring, perpetual refinement and prioritizing localization is poised to produce enduring societal benefits, balancing human ambitions with environmental needs.

STB endeavors in Erhai, which span water-environmental conservation, agricultural advancement and rural rejuvenation, apply an integrated approach across the natural and social sciences. For example, in the initial stages of enhancing the rice value chain, interdisciplinary teams encompassing environmental, ecological, soil sciences, agronomy, engineering and cultivation disciplines collaborated. Through their joint technological advancements, the STB targeted cost-efficiency, augmented yields and operational improvements. The subsequent stages necessitated collaboration across agricultural economics, cultural and industrial sectors to augment value and streamline the value chain. Integral to this entire endeavor was the collaboration of diverse stakeholders, from government agencies and businesses to STBs, cooperatives and farmers. Central to all these efforts is the commitment to uphold environmental safety and increased resource use efficiency. These tenets are foundational in mitigating non-point source pollution and championing superior agricultural practices. The ultimate vision remains clear: to boost farmer incomes and drive a green agricultural revolution that coexists harmoniously with environmental protection.

2.2 Participatory innovation required toward agriculture green transformation

To catalyze green transformation, the STB model in the Erhai Lake basin has established a collaborative platform. This platform convenes a diverse array of stakeholders, from local smallholders to scientific researchers and policymakers[39]. These multifaceted collaborations enhance the solution repository and bolster collective dedication to the green agricultural transformation. Within this framework, the model promotes participatory innovation, a characteristic of the STB approach, and a critical factor in its successful national implementation for supporting smallholders[15,16]. Green transition hinges significantly on technological advancements. In this context, participatory innovation becomes indispensable for the innovation, demonstration and diffusion of green technologies. This inclusive methodology harmoniously integrates local needs, advanced scientific expertise and adaptive strategies that are both innovative and pragmatic. This ensures their widespread acceptability and adaptability within the agricultural sector[14,39].

Initiated in the Erhai Lake basin in 2022, the Gusheng Village STB pioneered an advanced STB approach. Standard STB models frequently center on singular objectives, primarily anchored in technological innovations to invigorate industries and catalyze rural revitalization. In contrast, the Erhai initiative presents a more expansive and inclusive vision, simultaneously accounting for ecological, industrial, organizational modalities, talent cultivation and cultural rejuvenation. This experimental approach was achieved by assembling an experienced team of experts, drawing insights from a variety of disciplines, including non-point source pollution management, cutting-edge sustainable agriculture and contemporary rural renewal methodologies. The distinctive characteristic of the Erhai STB initiative lies in its dedication to multifaceted solutions. With an acute awareness that agricultural, ecological and sociocultural challenges are inextricably linked, the Erhai model underscores the imperative of adopting a comprehensive strategy. By promoting interdisciplinary collaborations, the Erhai STB ensures that devised solutions are not only grounded in solid scientific principles but are also implementable in real-world settings.

The close collaboration with the local farming communities acts as a grounding force for this initiative. By embedding itself within the community, the Erhai STB approach is strongly linked to the daily realities and challenges that farmers face. This intimate understanding ensures that the technological or process advancements proposed are not just theoretically sound but also pragmatically feasible and beneficial for the farmers. Also, the commitment Erhai initiative to holistic solutions means that while they prioritize ecological health, they concurrently focus on driving agricultural efficiency and enhancing economic prospects of farmers. In essence, the Erhai STB refined the STB approach represents a blueprint for

harmonizing environmental stewardship with agricultural prosperity, offering a model that other regions might consider emulating in their own unique contexts.

2.3 Goals of green technology diffusion through STBs

Green technology diffusion through STBs can be delineated into four stages (Fig. 1):

(1) Awareness and cognition: This step emphasizes both deepening farmer appreciation of environmental conservation and familiarizing them with state-of-the-art green cultivation techniques, mainly focus on decreasing fertilizer application according to common farmer practice. Additionally, researchers tap into traditional local knowledge about sustainable crop cultivation, ensuring that modern innovations are complemented by time-tested wisdom[40]. This combination creates a well-rounded foundation, equipping

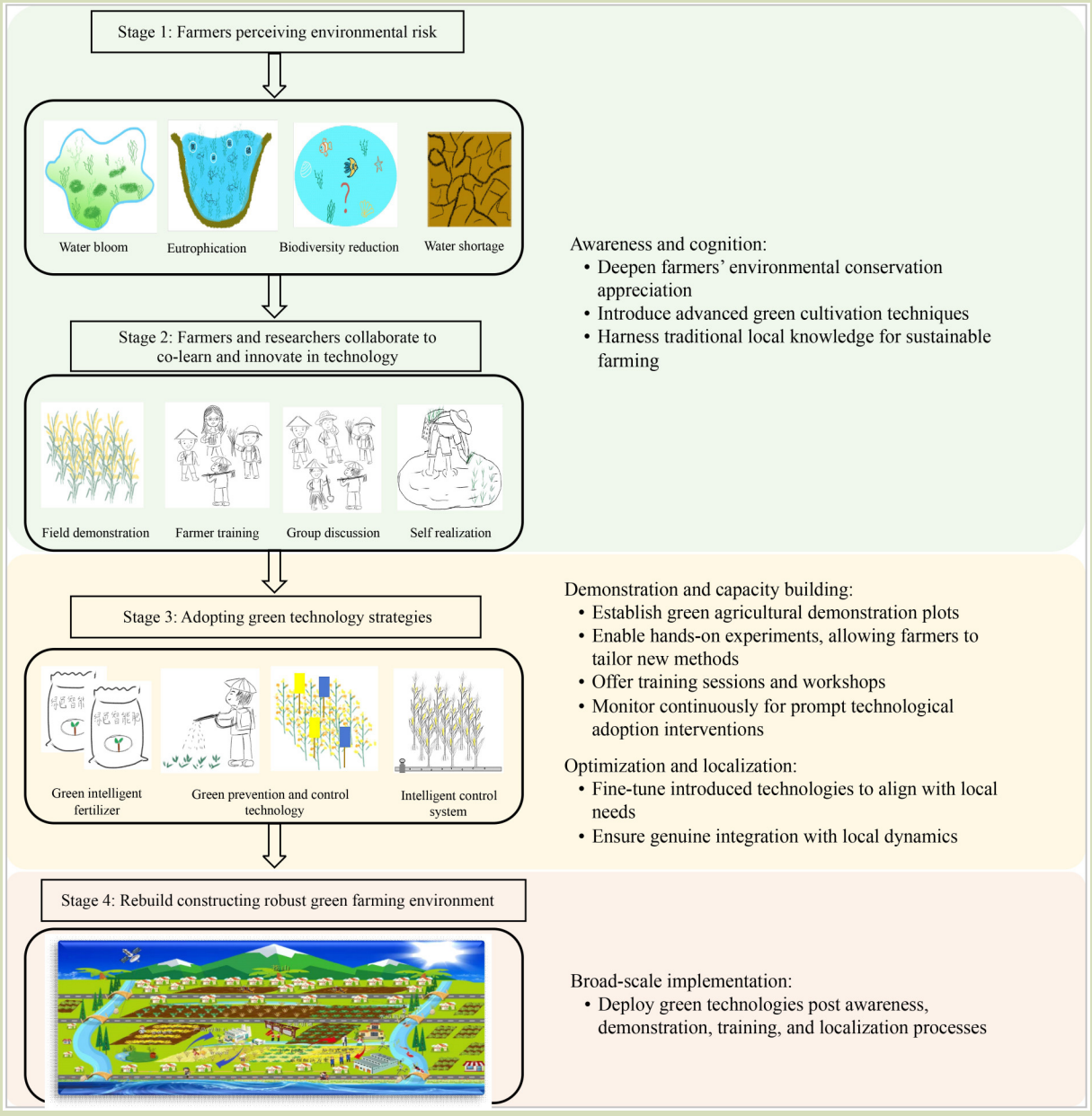


Fig. 1 Framework of green technology adaptation through Science and Technology Backyards (STBs). Modified from Ahmed et.al.[43] under Creative Commons.

farmers with a holistic understanding of sustainable agricultural practices.

(2) Demonstration and capacity building: Emphasis on the practical benefits of sustainable methods[15]. By setting up demonstration plots that highlight the efficacy of green agricultural practices (such as use green intelligent fertilizer to decrease the fertilizer use amount), farmers can witness firsthand the advantages of such techniques. Also, on-the-ground experiments are facilitated, granting farmers the autonomy to adjust and tailor new technologies to their specific local conditions, all under expert supervision. Dedicated training sessions and workshops bridge any knowledge gap between innovative solutions and grassroots applications. A significant part of this phase is dedicated to boosting farmer eagerness to engage with these new technologies, thereby enhancing their adoption rates. Continuous monitoring throughout the life cycle of the crop reveals any barriers to technology adoption, enabling prompt and appropriate interventions;

(3) Optimization and localization: Focus on fine-tuning the introduced technologies, which is marked by continuous assessments to ensure that these innovations align seamlessly with local requirements and challenges. The emphasis is on ensuring that these technologies are not just superficially integrated but are genuinely tailored to local dynamics [43];

(4) Broad-scale implementation: Encompasses a comprehensive deployment of green technologies, after the processes of awareness-building, demonstration, training and localization have been executed[16]. The goal is to ensure widespread adoption of these methods, transforming a significant portion of the agricultural landscape toward sustainability. In essence, this framework not only offers a structured approach for the seamless integration of green technologies via STBs but also underscores the indispensable contribution of farmers in this ecological paradigm shift.

3 Approach and impact of the Erhai STB in AGD

3.1 Smallholder transformation

In 2022, we started our work in the Gusheng Village STB following the principles of the top-down design of the Erhai STB complemented by bottom-up strategies. This initiative was designed to forge a new pathway that integrates Erhai conservation efforts with advanced agricultural development. It is crucial to understand that agricultural choices made at that time, given the biodiversity of the area, can influence the larger environmental landscape, including the health of the renowned Erhai Lake. The AGD approach, championed by the Erhai STB, is comprehensive. It entails a deep understanding of the local market trends, a reverence for the cultural heritage of the region, and a commitment to decisions that promote both environmental conservation and community prosperity (Fig. 2). Central to the AGD initiative in Erhai are the smallholders, who were key contributors due to their intrinsic connection with the land and its resources. Through the guidance of Erhai STB, smallholders are transitioning from basic farming roles to becoming stewards of their environment, promoting conservation while promoting growth.

Incorporating green agricultural technologies in Erhai means that smallholders must learn new techniques to lower the fertilizer application and effectively blend them with existing traditional practices. The AGD framework underscores the importance of continuous learning and critical assessment, especially in terms of how novel techniques integrate with local cultural norms and practices[32]. The strength of community networks, deeply embedded in the history of Erhai, cannot be underestimated. These networks are essential in disseminating knowledge and sharing resources, especially in a context where sustainable resource management, such as water use, directly impacts the health of the ecosystem (Fig. 2). The AGD framework accentuates that agriculture in Erhai is multifaceted encompassing local market insights and capitalizing on the cultural richness of the region, and is grounded in choices that prioritize both ecological balance and community development. In conclusion, the ongoing Erhai AGD initiative signifies the evolution of smallholders from simple farmers to proactive custodians of a delicate balance between ecology and sustainable development.

3.2 Transformation in farming practices through agricultural technological innovations

Gusheng Village STB set the goal of reducing the nitrogen and phosphorus runoff from farmland into the lake by 30% to 50% and increasing the value of output from 4000 to 150,000 CNY·ha^{-1}. As an early adopters of the STB approach, insights and best practices from Gusheng Village are anticipated to guide interventions in more villages in subsequent phases.

To pinpoint the origins of pollution, the STB designed a rigorous non-point source pollution monitoring network,

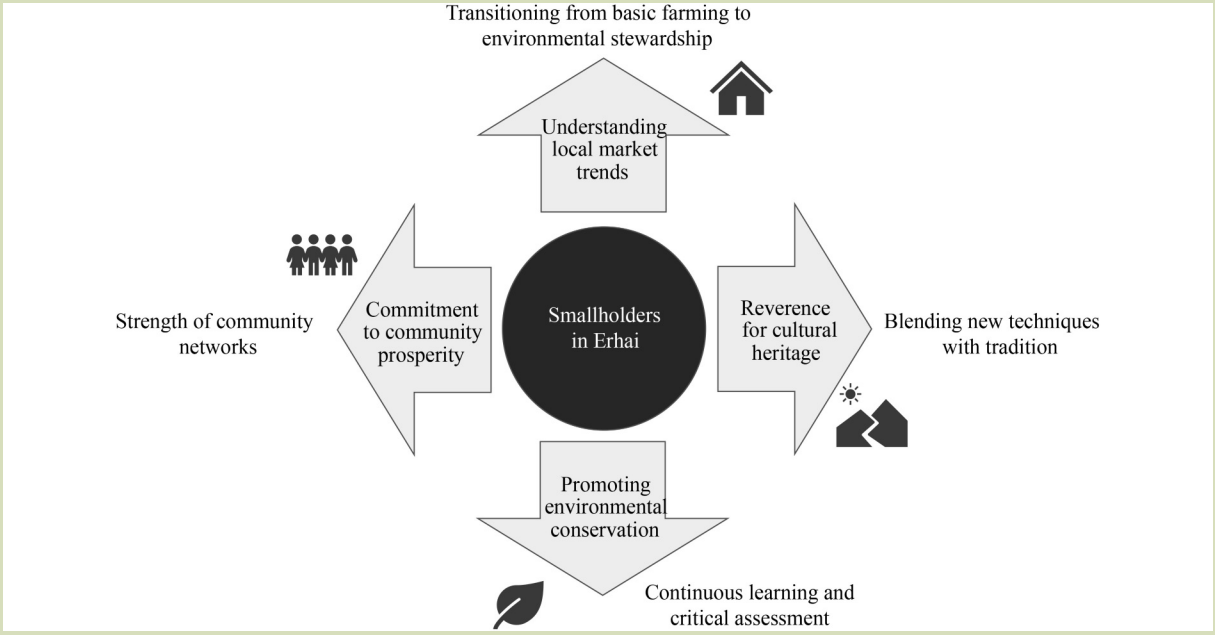


Fig. 2 Integrated Erhai Science and Technology Backyards (STBs) approach: bridging tradition, innovation and sustainability.

colloquially termed the *six verticals and seven horizontals* system. This extensive network encompasses 1556 households, 5235 land parcels, 1321 manhole covers, 22 waste disposal sites and 80 culverts. Over 1000 local personnel have been engaged in both regular surveillance and monitoring during intense rainfall. Throughout the initiative, we have collected and analyzed more than 3000 water samples across a 4.8 km^2 area spanning from the source of the Yangxi River in Cangshan Mountain through the village to Erhai Lake, a distance of 4 km. Our careful monitoring during different periods, including non-rainy seasons, rainy seasons and specific rainfall events, captured the entire pollution generation, transportation and discharge process. The water quality assays, accomplished both through automated online laboratories and manual laboratory testing, provided insights into parameters including total nitrogen, ammonium nitrogen, nitrate nitrogen, total phosphorus, dissolved phosphorus, chemical oxygen demand (COD), total organic carbon (TOC), silt content and chloride ions. Our preliminary findings from May to September 2022 revealed that about 80% of the pollution was attributed to agricultural non-point sources. A more detailed breakdown showed that farmland contributed 35% to 55% and village sewage about 40% of the pollution[44].

Aiming to reconcile environmental preservation with economic prosperity, we endeavored to empower the local farmers to grow crops that strike a balance between eco-responsibility and economic reward. This initiative birthed a sustainable agriculture model that emphasizes enhanced yield coupled with a reduced ecological footprint via careful nutrient management. Our approach commenced with a thorough investigation into the nutrient dynamics of different crops to strike a balance between supply and demand. We then incorporated green technologies tailored for increased production efficacy, leading to the establishment of an annual cultivation model that accentuates both ecological and economic sustainability. Practically, this involved the deployment of green intelligent fertilizer (matches soil, crops and climate and environmental conditions) and biodegradable mulches to conserve soil moisture and nutrients. At our demonstration site, we observed significant agricultural and environmental benefits. Specifically, rice yields were boosted by 31% to 12,120 $kg{\cdot}ha^{-1}$ and profits soared by 23,850 $CNY{\cdot}ha^{-1}$, while phosphorus runoff dropped by 50% and COD by 52%. To ensure sustainable high-value cultivation with the goal of yearly financial goal of 150,000 $CNY{\cdot}ha^{-1}$, high-value crops such as multifunctional rapeseed and sweet corn were introduced in our innovative cropping systems. Notably, the multifunctional vegetable-flower-oil rapeseed program delivered 20% and 19% reductions in phosphorus and nitrogen loss from farmland, respectively, a 50% increase in oil output, prolonged the flowering period by 10 days, and an extra 67,500 $CNY{\cdot}ha^{-1}$ a profit through vegetable sales.

3.3 Whole village transformation

Since the establishment of the STB in Gusheng Village, its influence has extended beyond just facilitating green agricultural technological advancements. The socioeconomic impacts have been profound. In 2023, we undertook an in-depth village assessment using a blend of structured questionnaires and comprehensive interviews with villagers and local leaders. The findings, as shown in Fig. 3, suggest that according the villagers and their leaders, the STB was pivotal in augmenting earnings of villagers across wage, property and business sectors in 2022. Through this survey, we found that the introduction of STB protocols and practices directly resulted in an estimated income increase of about 6.25 million yuan for the village (Fig. 3(a)), thereby raising the average annual farm income by 3395 yuan (about 1800 persons live in the village). Through the STB initiatives, farmers have diversified their revenue streams, exploring various channels such as wage earnings, property leasing and entrepreneurial ventures.

On a sociocultural level, an overwhelming majority (> 90%) of Gusheng farmers recognized the positive effect of the STB on the development trajectory of the village (Fig. 3(b)). Notably, nearly half of the villagers engaged in at least one training event organized by the STB. These training sessions encompassed a spectrum of themes, from introducing green farming

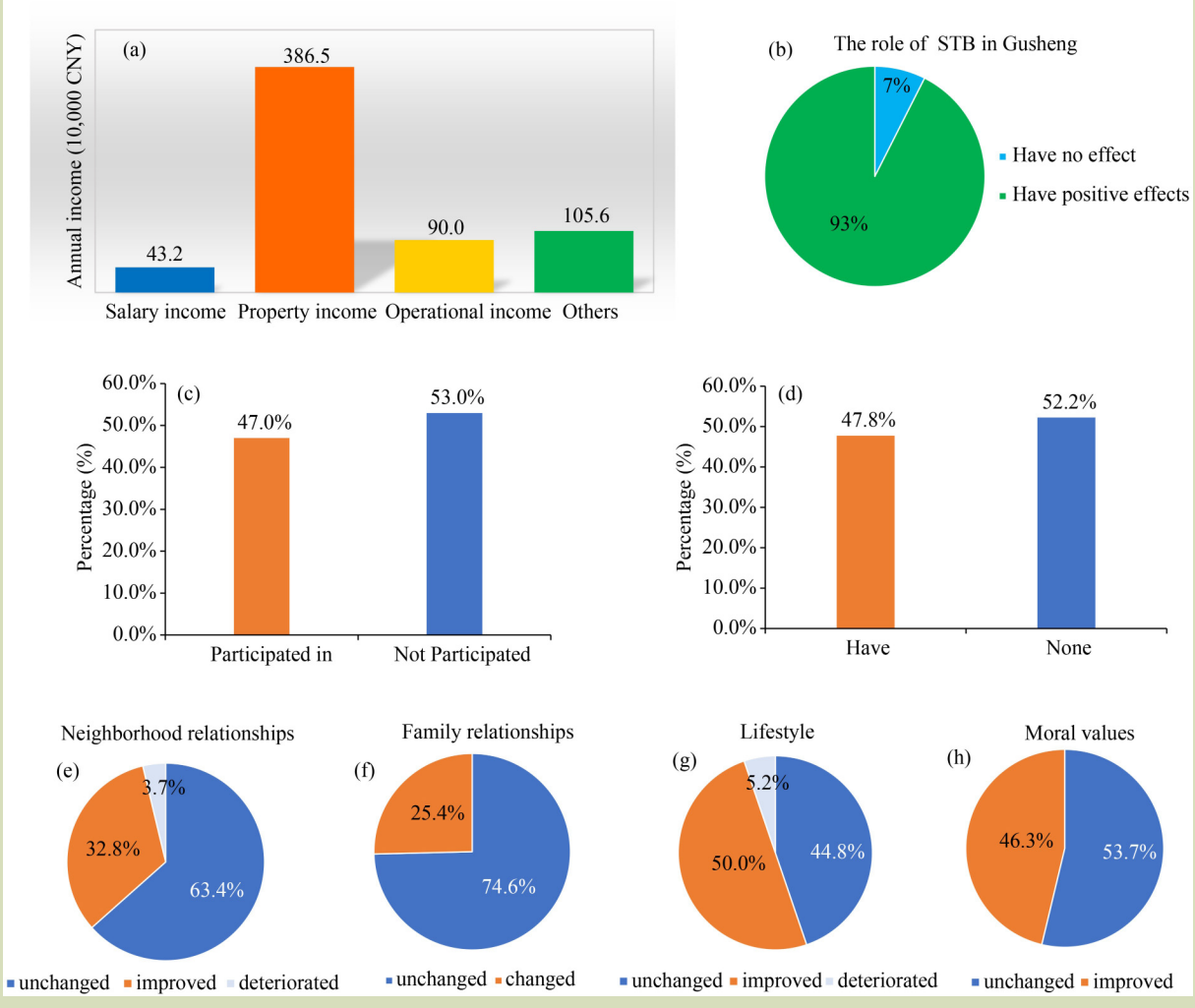


Fig. 3 Socioeconomic impact on Gusheng Village after the Science and Technology Backyard (STB) was established by: (a) income change in the village, (b) perceived effect of the STB; (c) attendance rate of local farmers of training activities hosted by the STB, (d) percentage of local farmers having an interest in the training topics, (e) perceived changes in neighborhood relationships, (f) perceived changes in family relationships, (g) perceived changes in lifestyle, and (h) changes in the perception of moral values.

methodologies to influencing lifestyle shifts geared toward water preservation and pollution mitigation. Topics delved into the emphasis on the health benefits of dietary changes, the importance of waste sorting, understanding household water contaminants, and more. Post-training assessments showcased a promising trend: 53% of participants had adopted at least one sustainable practice or modified their lifestyle (Fig. 3(c,d)). For example, a noticeable fraction of villagers started classifying household trash and refining their diet, cutting down on salt and oil, thereby endorsing both individual health and environmental stewardship (Fig. 3(g)). Our analysis also highlighted a correlational increase of 33% and 25% in enhanced familial and communal ties, respectively, most likely spurred by the improved incomes (Fig. 3(e,f)). Intriguingly, academic pedigree of the STB seems to have catalyzed a renewed focus on education. Over half of the interviewed villagers expressed a renewed commitment to the academic pursuits of their children. Adding a cultural dimension, the active involvement of STB researchers in the traditional activities of the village has invigorated local cultural pride (Fig. 3(h)).

4 Perspectives

The Erhai AGD initiative in Gusheng Village exemplifies how environmental conservation can be effectively integrated with agricultural innovation. This initiative covered a range of areas, from controlling non-point source pollution to fostering value-added agriculture, strongly advocating the benefits of interdisciplinary collaboration (Fig. 4). A key aspect of the Erhai STB initiative is its dedication to achieving a fine balance between rigorous environmental protection and enhancing farm incomes. This approach is pivotal to the primary aim of the initiative; to ensure environmental health while boosting the economic well-being of local smallholders. The fusion of ecological priorities with economic improvement is evidence of the comprehensive and well-grounded strategy of the initiative. By emphasizing these dual goals, the initiative aims to progress ecologically without compromising the financial stability of the farming community (Fig. 4).

At the heart of the Erhai STB initiative is its commitment to sustainable agriculture, which blends environmental science, innovative agricultural methods and cultural insights. The

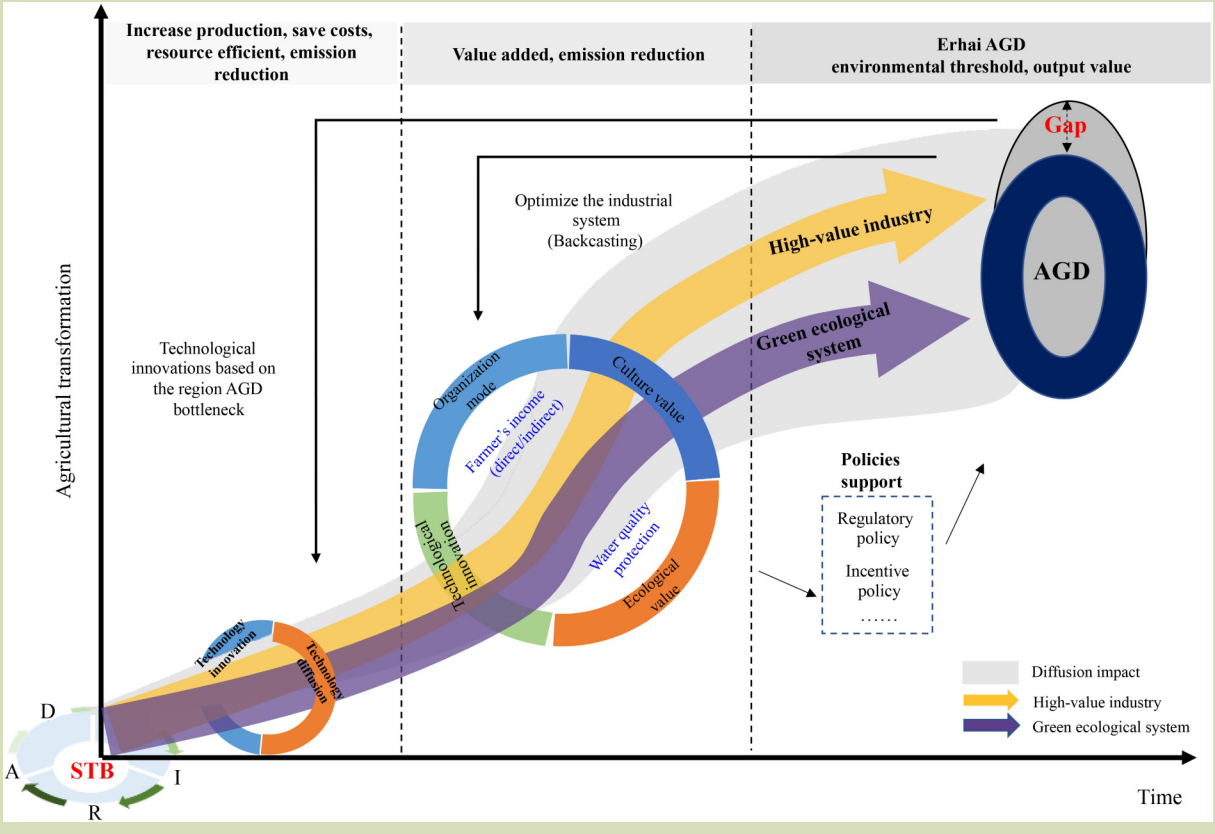


Fig. 4 The framework of Erhai Science and Technology Backyard (STB) approach.

unique approach to environmental conservation in Erhai through green technology, particularly its focus on local rotational planting systems (such as rice-rapeseed, rice-faba bean, maize-vegetables and tobacco-rapeseeds crop rotations) and water conservation techniques, demonstrates its strong commitment to sustainable practices (Fig. 4). Despite the unique challenges presented by the distinct geographical and climatic conditions of Erhai, the strategy of the initiative to intertwine environmental and economic objectives aligns with the progressive agricultural vision of China. By prioritizing customized strategies over multipurpose solutions, the Erhai STB offers valuable insights for the global evolution of agriculture.

Sustainable funding is crucial for the success of the Erhai STB. Collaborations with government bodies such as the Yunnan Province and the Dali Governments, alongside partnerships with the corporate sector, have been instrumental. These alliances not only strengthen the financial foundation the initiative but also emphasize its broader economic goals, particularly the prosperity of smallholders. Researchers involved in the initiative are also encouraged to align their individual research efforts with the broader objectives of the initiative, fostering a synergy between financial resources and research activities. However, the initiative has faced challenges, particularly in integrating diverse academic disciplines, which has sometimes led to extended research timelines. Collaboration with local governments, while beneficial, has occasionally introduced bureaucratic hurdles. Aligning the diverse interests of stakeholders, from academics to farmers, has required careful negotiation and strategy. A key challenge has been ensuring that environmental protection efforts do not inadvertently compromise farm incomes, reflecting the commitment of initiative to balancing ecological preservation with smallholder economic prosperity.

From the insights of the Erhai STB initiative, several policy implications emerge. One notable observation is the need for a comprehensive environmental management strategy, as highlighted by the significant pollution contribution from sources such as sewage in Gusheng Village. Shifting toward community-centric policies is crucial, underlining the importance of grassroots participation and empowerment. Implementing financial incentives could boost the adoption of sustainable agricultural practices, acting as catalysts for change. Establishing dynamic, data-driven monitoring frameworks is essential. Adopting global best practices and fostering international collaborations can enhance the Erhai STB model. Importantly, directing research funding toward farmer-focused initiatives can be key in simultaneously promoting environmental conservation and economic growth.

In conclusion, the Erhai STB initiative, by combining environmental conservation with green technology adoption and a strong focus on improving smallholder incomes, highlights the importance of ongoing research and adaptation in the pursuit of a more sustainable and prosperous agricultural future. The long-term vision for the initiative anticipates it becoming self-sustaining as farmers gain expertise and independently implement learned sustainable practices. Once a systematic solution is established and shared with local government, the external experts aim to transition their focus to other regions with similar problem areas, spreading the knowledge and success of the Erhai STB model. This approach not only ensures the scalability of the model but also fosters a culture of sustainable agricultural practices that can be adapted and applied across diverse environments.

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Compliance with ethics guidelines

Kemo Jin, Nico Heerink, William J. Davies, Jianbo Shen, Yifeitong Zhang, Yong Hou, Yaqiao Zhao, Zhengxiong Zhao, and Fusuo Zhang declare that they have no conflicts of interest or financial conflicts to disclose. This article does not contain any studies with human or animal subjects performed by any of the authors.

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