Measuring what matters in sustainable rice production

TEEBAgriFood Thailand EU-funded project

Scope and Methodology Report

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TEEB
The Economics of Ecosystems & Biodiversity

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Introduction and background

1. TEEBAgriFood initiative in Thailand

A transformative change in food systems is needed in order to meet the internationally agreed Sustainable Development Goals. The Economics of Ecosystems and Biodiversity for Agriculture and Food (TEEBAgriFood) initiative was developed by the UN Environment Programme (UNEP) in response to this need and seeks to achieve positive human livelihood outcomes and biodiversity improvements. The overall programme goals are to measure and mainstream the values of nature in decision-making and policy, to highlight the hidden, and often invisible, contributions of nature to agricultural production, and trade-offs made in land-use decisions, to highlight links of agricultural systems with human health, culture, and other ecosystems at the landscape level, and based on this scientific research, to work with partners and key stakeholders on pathways to implementing reform of national policies and measures for meeting the Sustainable Development Goals by 2030.

The TEEBAgriFood Evaluation Framework and approach was developed through a collaboration of scientists from many different countries and disciplines. This approach is synthesized in the report "Measuring What Matters in Agriculture and Food System" (UNEP, 2018) and described in more detail in the "TEEB for Agriculture & Food Scientific and Economic Foundations" report (UNEP, 2018). The key components of the framework are illustrated below in Figure 1, highlighting the dependencies of the rice system upon stocks of natural, produced, social and human capitals and the value additions and impacts that the rice production system generates.

Based on the inception workshop for the TEEBAgriFood initiative in Thailand in 2018, the rice sector was selected as the key focus for the TEEBAgriFood in Thailand. Rice production is integral to Thailand's culture, agricultural landscapes and rural livelihoods. About 20 percent of the nation's households, or 4.30 from 21.58 million households, are rice farmers (National Statistical Office, 2019). Significantly, the rice cultivation area extends over 50 percent of total agricultural area in Thailand, about 9.59 million hectares (Office of Agricultural Economic, 2020). The cumulative impacts of production practices at farm level are therefore significant not only at regional level but also at national and international levels. Rice production generates just under 25 percent of all raw agricultural produce in Thailand. Moreover, several agricultural industry products are developed from rice output. Rice production is not only significant for Thailand but also for global food security. Despite its relatively small area, Thailand is one of the top three rice exporters in the world (FAOSTAT, 2020).

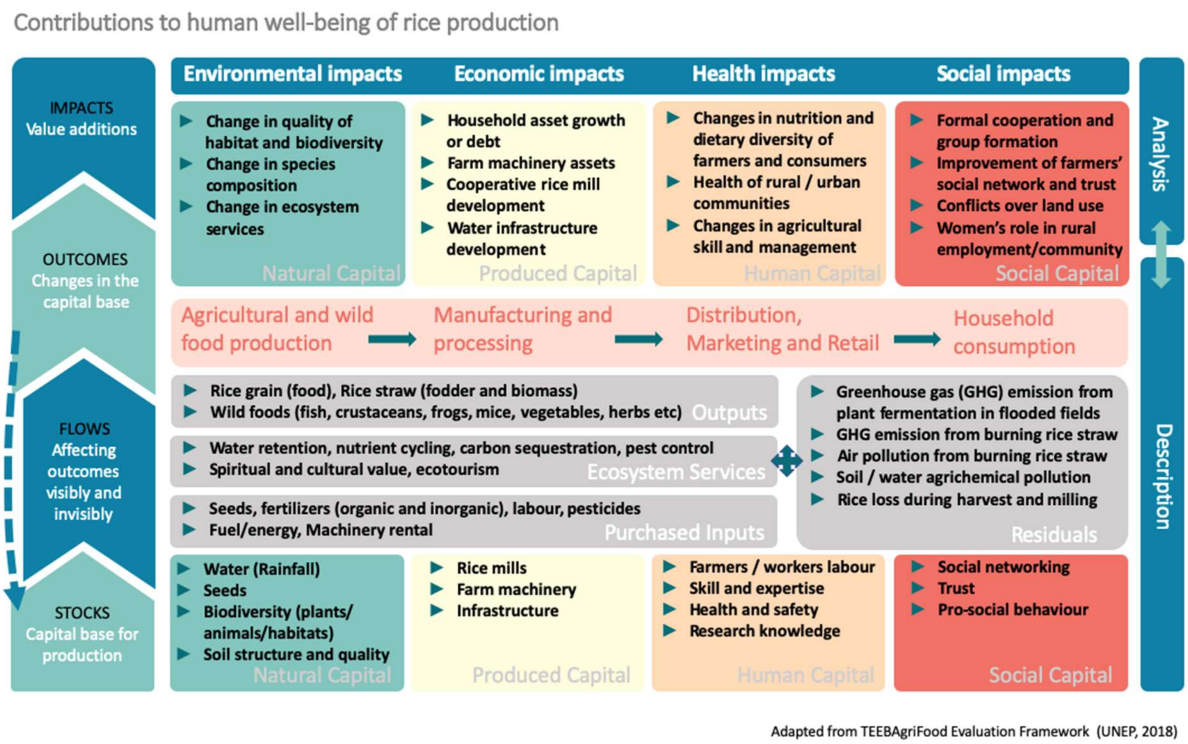

Figure 1: TEEBAgriFood evaluation framework applied to the rice sector

1.1 Visible and invisible costs and benefits

As illustrated by the TEEBAgriFood evaluation framework in figure 1 above, rice production is dependent on the resources of natural, human, social and produced capital, as well as the flows of inputs and outputs throughout the agricultural value chain that interact with ecosystem services and residual processes. In combination, these flows create changes and impacts on natural, human, social and produced capitals, and ultimately, if the system works well, should contribute overall to human well-being.

Within this picture, purchased inputs and labor are the most visible contributions to rice production, and the economic value of the harvest is often analyzed in these terms, and influenced by local and global market demand and supply and other operational costs. However, the rice economy should not ignore all the other contributions to the production of rice, just because they exist outside the framework of the market. These "externalities" generate values that may be equally, or in some cases such as public health and cultural heritage, that may be even more important to Thai society. If the production system, including the later stages of the supply chain from farm to fork, progressively undermine the capitals on which Thailand depends, then this system is not sustainable over the long term. Thailand relies on these capitals for its rice harvests, for other critical production systems, and for well-being of the Thai people.

The TEEBAgriFood project aims to institutionalize a process that incorporates of the main key values of rice production in decision-making. We want to understand not only what is gained in terms of revenues, and spent in terms of production costs, but also the gains and costs in natural, human and social capital. When policy makers include the full range of costs and benefits in decision making, they should be better able to manage the system toward sustainability. The goals of food security and income security, improving environmental and health impacts are important and interdependent, and reaching them is likely to require trade-offs. This assessment will shed light on how to reduce trade-offs between these different goals, and to identify synergies that allow for maximizing benefits and the better well-being of farmers, while minimizing costs to environment and society.

2. Summary of TEEBAgriFood Thailand assessment on organic rice

The TEEBAgriFood assessment in Thailand funded by International Climate Initiative (IKI" project") was completed in June 2022. In summary, this project sought to measure and make visible diverse costs and benefits of rice production as a means to identify options for promoting long term sustainability of production and management of rice landscapes. A scenario analysis was prepared based on projected land use changes from conventional to organic rice practice.

Four scenarios were developed to understand potential future impacts of government policies, including the One Million Rai Organic Rice promotion policy, and Parliamentary targets for achieving sustainable agriculture by 2030. This analysis demonstrated the potential trade-offs generated as organic rice production practices in Thailand are extended over an increasingly large area of the North East of Thailand, over the period 2019-2035. Project outputs are available online (https://teebweb.org/where-we-work/asia-pacific/thailand/).

The key conclusions of the organic rice assessment were as follows:

1. To reach the aims of the Bio-, Circular, and Green Economy model in Thailand of more sustainable growth and more environmental responsibility, a transition is needed towards fully sustainable rice production and sustainable landscape management.
2. The impact of changes needs to be assessed at the landscape level, as farm-level results give an incomplete picture because they fail to capture the full range of impacts, externalities and dependencies in the system.
3. It is important to make visible the connections between nature and rice food systems by quantifying the oft invisible flow of benefits from ecosystems to food systems and human well-being. This involves identifying where, how much and to whom nature provides benefits, showing the impacts of Business As Usual, and what would be the comparative impacts under alternative agri-environmental planning policy scenarios for the future.
4. Rice yields are affected by cultivation practices, seeds, and environmental conditions. Often, when considering whether a switch to organic from conventional is viable and desirable, it is assumed that rice yield under organic production will be diminished in the short to medium term. However, the findings of this study project relatively minor losses, both in terms of volume output and dollar value, as a result of adopting the alternative scenarios relative to BAU.
5. The emission of greenhouse gases (GHG) from rice fields is generated by cultivation practices (organic fermentation), post-harvest practices (stubble burning), and mitigated by soil carbon sequestration. The expansion of organic rice area as projected in the alternative scenarios 2, 3 and 4 would reduce overall GHG emissions, due to the stubble burning prohibition and high soil carbon accumulation in organic rice fields. Overall, organic rice practice generates lower overall GHG emissions per hectare than conventional rice practice.
6. Biodiversity is affected by cultivation practices. With expansion of organic rice, agro-biodiversity increases, especially insect varieties, at landscape level, which promotes natural pest control.
7. The impacts of conventional rice production have negative externalities on human health. The analysis found that policy pathways for organic rice expansion improve human health, through reduced exposure to pesticides and air pollution.

8. Organic rice production generates other benefits to human wellbeing for society, food, and culture.
9. Farmers' decision to adopt and/or continue to grow rice organically depends on policy support, particularly during the transitional period, and price incentives.

The key policy recommendations developed from the assessment were as follows:

- The main subsidy policies in agriculture have been focused on reducing farmers' financial hardship, but this does not encourage farmers to adopt more sustainable practices. To induce farmers to adopt organic practice, subsidies need to be reoriented, conditional on adopting sustainable agricultural practice, such as organic rice practice.
- On average, organic rice yields are lower than conventional rice yields, but not significantly so. The loss of income from the marginally lower yield for organic farmers would be directly offset as long as farmers can sell their organic rice at a price that is least 3.5 percent higher than that of conventional price.
- Organic rice practice generates positive externalities through health and environmental improvements. However, when these positive externalities cannot be completely included or realized by market system, government should step in to minimize market distortion to ensure the public still benefits from positive externalities generated by organic rice farmers activities. In addition, organic rice farmers receive not only positive returns from cultivation cost reduction and health improvement but also generate positive return to their local community and wider society.
- Exporting organic rice to international market requires different certifications depending on countries. To share cost of getting certification to ensure profitability for farmers, policies aimed to enhance more organic rice production should focus on promoting the grouping of farmers into discreet areas that can be certified as organic instead of at individual level.

3. Introducing the TEEBAgriFood Thailand assessment on sustainable rice

3.1 Global project outline

The scope of the global project financed by the European Union Partnership Instrument (EUPI) is to protect biodiversity and contribute to a more sustainable agriculture and food sector in seven countries (Brazil, China, India, Indonesia, Malaysia, Mexico and Thailand). The Economics of Ecosystems and Biodiversity (TEEB) Evaluation Framework will be used to test interventions that have already been applied or are proposed to stimulate positive livelihood and biodiversity benefits, and assess whether and to what extent they produce hidden or unaccounted for outcomes on natural, human, social and manmade capitals. Importantly, the focus of the project is on biodiversity and ecosystems, which underpin the delivery of the Sustainable Development Goals. The project will bring together governments, business and other key actors from civil society to implement activities with a view to influencing decisions and behaviors.

3.2 Focus in Thailand

The research scope will be a TEEBAgriFood assessment of commercial rice sector who are receptive to looking at dependencies and impacts on biodiversity and ecosystem services. This work would focus on sustainable production practices as advocated under the Sustainable Rice Platform (SRP) [1] Standard for Sustainable Rice Cultivation (SRP Standard). The study will focus on clarifying the effects of specific cultivation practices relevant to the SRP Standard on natural capital, human capital, social capital, and produced capital following TEEBAgriFood Evaluation Framework.

3.2.1 Sustainable Rice Platform (SRP), SRP Standard, and GAP++

The Sustainable Rice Platform (SRP), established in 2011 by internationally organizations such the International Rice Research Institute (IRRI), the United Nations Environment Programme (UNEP) and Deutsche Gesellschaft für International Zusammenarbeit GmbH (GIZ), aims to transform the global rice sector through voluntary market transformation towards sustainable production practices. It focuses on improving smallholder livelihoods, reducing the social and

[1] For more information of the Sustainable Rice Platform (SRP), https://www.sustainablerice.org/

environmental footprint of rice production, promoting resource efficiency, reduced carbon emissions and resilience to climate change.

The SRP Standard is an internationally accepted sustainability standard for rice, which comprises 41 requirements structured under eight themes (see figure 2). The Standard presents a framework to support claims to sustainability.

In Thailand, the Rice Department of the Ministry of Agriculture and Cooperatives have drafted a new GAP Standard for Rice that is consistent with the SRP Standard and adapted to the Thai context. This is colloquially referred to as the "GAP++" Standard for rice. Specifications are available online in Thai from the Bureau of Agricultural Commodities and Food Standards ACFS (www.acfs.go.th/files/files/commodity-standard/20220602160717_661890.pdf). The GAP++ Standard is currently being introduced to farmers through the Thai Rice NAMA project in Ayutthaya, Ang Thong, Chainat, Sing Buri, Suphanburi, Pathum Thani, and Ubon Ratchathani (https://www.thai-german-cooperation.info/en_US/mainstreaming-sustainable-rice-through-the-sustainable-rice-platform-project/).

The TEEBAgriFood analysis will focus on five key management practices that promote sustainability which relate directly to the SRP themes of "biodiversity" and "greenhouse gas emissions".

Figure 2: SRP Standard comprises 41 requirements structured under eight themes

3.3 Key partners

Steering Committee

TEEBAgriFood Thailand is an initiative under the political lead of the Office of Natural Resources and Environmental Policy and Planning, ONEP, in the Ministry of Natural Resources and Environment.

The Steering Committee engages agencies within the Ministry of Natural Resources and Environment including two offices within ONEP, the Climate Change Management and Biodiversity Management Offices, the Department of Pollution Control, and the Department of Environmental Quality Promotion. Agencies engaged within the Ministry of Agriculture and Cooperatives include the Department of Agriculture, Department of Agriculture Extension, Department of Fisheries, Department of Livestock Development, National Bureau of Agricultural Commodity and Food Standards, and the Rice Department.

Three additional agencies have been added to the Steering Committee: The Fiscal Policy Office, within the Ministry of Finance, the Department of Disease Control, within Ministry of Public Health, and Department of Internal Trade, within the Ministry of Commerce. In addition, the Committee includes a representative from the Office of the National Economic and Social Development Council.

Research team

The Economics Faculty of Khon Kaen University is the host research institution of the TEEBAgriFood Thailand Initiative, leading a team of researchers from local universities and government agencies to carry out a multidisciplinary analysis of rice agroecosystems.

Donor and project support

The TEEBAgriFood project is managed by UNEP with the funding and project support from the European Union through the European Partnership Instrument, with the support of the EU Delegation in Bangkok.

Private sector engagement

The TEEBAgriFood initiative engages private sector groups in transformation of the agrifood sector through a parallel set of activities under the TEEBAgrifood for business project. This seeks to support private sector actors to understand the complex ways in which they depend and impact on the health of ecosystems for their success, and provide a clear business case for investing in environmental protection and restoration. The project will identify areas where nature-based solutions can be implemented to deliver benefits for business, nature and communities and develop collaborative partnerships at regional and national levels between key players in the agri-food value chain.

The Capitals Coalition, in collaboration with UNEP and the partners of the TEEBAgriFood initiative, have developed a series of activities with national business network partners, including the Global Compact Network of Thailand and the Scholars of Sustenance.

In addition to these activities, the public sector component of the project which is described in this report, is seeking to engage private sector agencies within the membership of the Sustainable Rice Platform, who are operating in the commercial rice sector in Thailand to seek their perspectives on the adoption of project results to make the business case for investing and incentivizing sustainable rice practices.

International partners

The TEEBAgriFood initiative is being developed by UNEP in Brazil, China, India, Indonesia, Mexico, Malaysia and Thailand in collaboration with local partners, with the support of the European Union Partnership Instrument. Opportunities for South-South exchange and learning are organized throughout the project to include government partners, research partners and private sector representatives engaged in each country.

3.3 Analytical approach

The research goes beyond comparing different rice production practices or systems, to include an analysis of the comparative impact of concrete policy instruments, frameworks and pathways at the national and subnational level. These different policy intervention scenarios will be analyzed in terms of changes in stocks and flows of produced, natural, social and human capital.

Policy recommendations will put forward initiatives to achieve greater gains for sustainability of rice systems using the following approach:

- The analysis is forward-looking, applying predictive modeling: scenarios allow the presentation of information on the comparative change in four capitals under the application of different policy initiatives, instruments or programmes. This would allow decision-makers (regulators, agri-businesses and farmers) to see the trade-offs that arise through application of different policy measures, as compared with Business-As-Usual (BAU).
- The analysis is carried out at the landscape level. Spatial models generate results at a local/regional scale (e.g., watershed level) and present them on a map; Analysis at this landscape level (beyond farm-level or narrow crop focus) takes into account landscape configuration (for example habitat fragmentation) and context (for example proximity to landscape features such as watercourses), as these are key factors in determining impacts on many ecosystem services and biodiversity.
- The analysis seeks to link science and policy processes at an early stage. TEEB Country Studies are social processes - co-creation process by policymakers, the scientific community and other stakeholders forms an important part of the achievement. It will be important not only to engage the Office of Natural Resources and Environmental Policy and Planning (ONEP), and the Ministry of Environment and Natural Resources, which Chairs the Project Steering Committee, but also to reach out to key stakeholders from other relevant Ministries, including the Ministry of Agriculture and Cooperatives, Ministry of Finance, and the Ministry of Public Health, private sector and civil society groups.

The project will also develop work to mainstream the findings of both the initial and follow up TEEBAgriFood studies on rice in Thailand into the training activities and materials used by the government's agricultural extension services.

4. Key differences between this analysis and the initial IKI-funded analysis

The main differences between IKI and EU-PI project are the rice practices considering, study areas, time period of study, and types of crop cultivation as summarized in the table below.

Table 1. The main differences between IKI and EU-PI project.

Issue	IKI funded (completed 2022)	EU-PI funded (ongoing to 2023)
Comparing commercial rice sector with	Organic rice Standard practice	SRP Standard (represented by adoption of 5 key practices outlined in next section)
Main comparison rice practices focusing	No chemical use and no stubble burning	Based on requirements of the SRP Standard related to biodiversity and greenhouse gas performance indicators, including Alternate Wetting Drying (AWD)[2], cover cropping, suitable fertilizer and chemical input use, and stubble burning prohibition
Study areas	Mainly in Northeast which about 90% is non-irrigated areas.	The Central region, which 75% of the areas could access irrigation, in addition to the Northeast which cover over 80 percent of rice cultivation area in Thailand.
The temporal scope of the study	17 years from 2019 to 2035	Extended to 28 years from 2022 to 2050 to relate with Thailand carbon neutrality in 2050 as the World Leaders Summit of the United Nations Framework Convention on Climate Change Conference of the Parties (COP26).
Diversification of land management	Focusing only on rice	Extended to crop rotations in rice irrigation areas during dry season which improve soil quality.

[2] Alternate Wetting Drying (AWD) is "a water management practice where irrigation is applied at intermittent intervals resulting in alternating wet and dry soil conditions, …. which can save irrigation water without yield penalty." SRP. (2020)

Part 1: Thai policies and plans to transform agricultural sector

1. National level policies and strategic plans for transformation to sustainability

Thailand's 20-Year National Strategy (2018-2037)[3] emphasizes sustainable development and inclusive growth. The sub strategy in the topic of agriculture and sustainable development highlighted promoting safe, biological and smart agriculture, green economy, ecosystem services and environmental quality. Sustainable agricultural products and improving the air quality index have been targeted in the strategic plans.

The Ministry of Agriculture and Cooperatives (MOAC) has enacted the 20-year Agricultural and Cooperatives Strategy (2017-2036)[4], which focuses on promoting farmer institutions, increasing farming efficiency, escalating the adoption of product standards, boosting agricultural competitive advantages through the use of technologies, and balancing agricultural resource use with sustainability. One of the targets is to increase the area of sustainable agriculture from 0.81 million rai (0.13 ha) in 2017 to 10 million rai (1.6 million ha) in 2036.

The shorter-term 13th National Development plan (2023-2027)[5] also contains the target of sustainable agriculture, which is more challenging as it sets a target to increase the area under sustainable agriculture to 10 million rai (1.6 million ha) by the end of 2027.

Climate change is one of the main risk factors affecting the agricultural sector. The MOAC developed the Agriculture Climate Change Strategy (2017-2021) [6], which focuses on reducing GHG emissions by using environmentally friendly technologies in agricultural production such as reducing post-harvesting burning, soil management to improve soil carbon stocks, and promoting low carbon agricultural standards.

The National Master Plan on Climate Change (2015-2050)[7] has been introduced by Office of Natural Resources and Environmental Policy and Planning (ONEP). In the topic of agricultural sector, this plan promotes water management for flooding and drought, crop-zoning strategy, biodiversity and biological technologies, as well as maintaining ecosystem richness. Besides focusing on GHG emissions reductions from the industry and transportation sectors, this plan also

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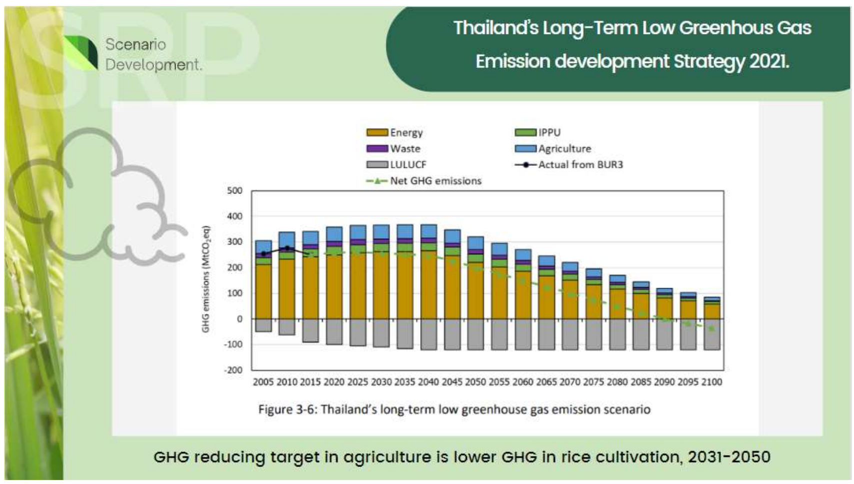
[3] http://nscr.nesdc.go.th/ns/
[4] www.oae.go.th/assets/portals/1/files/bapp/strategic2560-2579.pdf
[5] www.nesdc.go.th/main.php?filename=plan13
[6] https://old.alro.go.th/research_plan/ewt_dl_link.php?nid=1888&filename=index
[7] https://climate.onep.go.th/wp-content/uploads/2019/07/CCMP_58-93_TH.pdf

targets to reduce GHGs emission from agricultural sector, which includes reductions of post-harvest stubble burning, rice cultivation, and promoting low carbon agricultural standards.

At the World Leaders Summit of the Conference of the Parties in 2021 (COP26), Thailand proposed to reach carbon neutrality by 2050, and net zero GHG emissions by or before 2065. The main roadmap to reduce CO_2 for carbon neutrality in 2030 was mainly focused on the energy, transportation, waste management, and industry sectors. The agricultural sector is not yet highlighted in the road map for reaching net zero GHG emissions by 2065. However, the issue of agricultural sector in waste management, sustainable agriculture, and low carbon cultivation were mentioned.



Moreover, the Bio-Circular-Green (BCG) Economy model has been endorsed as the national strategy for Thailand to escape from the middle-income status trap in 2021-2027[8] which supports sustainable development goals. One of main strategies is to promote sustainable agriculture.

2. Policies and plans for sustainable rice production, healthy agricultural practices

To promote sustainable rice production, environmentally-friendly rice cultivation standards have been progressively adopted in Thailand. The Thai Good Agricultural Practices (GAP) Standard introduced under the Agricultural Standards Act (2008) [9] aims to encourage

[8] https://climate.onep.go.th/wp-content/uploads/2019/07/CCMP_58-93_TH.pdf
[9] https://www.acfs.go.th/standard/download/eng/GAP_Food_Crop.pdf

farmers to produce agricultural products that are safe for consumers. The GAP+ program and GAP++ program was later introduced to extend the related Standard including verification of product quality, ensure farmers safety, and certification of GHG emissions reductions. The Standard referred to as “GAP++ for Rice” was developed on the basis of Standard of the Sustainable Rice Platform (SRP) and is currently supported under the progress of the Thai Rice NAMA project[10].

The government’s Thai rice Nationally Appropriate Mitigation Action (Rice NAMA) project in collaboration with GIZ (2018-2023) aims to help farmers in the central part of the country to start applying low greenhouse gas emission methods, as a step towards the development of “low-carbon” rice products.

In addition, the Thai Organic Agriculture Standard was promoted under the National Organic Agriculture Development Strategy (2017-2021, BE. 2560-2564). The Organic Rice Standard developed by the Rice Department has been generated to support organic rice production that qualifies for the Organic Thailand certificate. More information about this Standard can be found in the full findings report of the TEEBAgriFood (IKI-funded) project on the expansion of organic rice.

The government also promotes the public awareness of safe food and certified agricultural products that directly link to consumer health in order to promote a change in public attitudes and consumer behavior. Thailand’s public health policy relating to the safety of agricultural food is also aligned with the agricultural pesticide regulations. The National Hazardous Substances Committee decided in 2019 to ban the herbicide paraquat and insecticide chlorpyrifos with effect from June 2020. The use of the herbicide Glyphosate was restricted by this Committee at the same time, and can be used only in certain agricultural activities, including conventional rice cultivation, as long as this is approved and supervised by local authorities. The Ministry of Public Health has supported to ban these three pesticides by educating farmers and tracking pesticide contamination in farmers’ blood for awareness raising.

To increase farming efficiency, the Rice Mega Farm scheme was introduced since 2017 to encourage sharing economy in rice farms, to improve economies of scale including in farm planning, product marketing and distribution, and to support farmer institution and technology

[10] https://www.nama-facility.org/news/nama-facility-funding-approved-to-support-the-implementation-of-the-thai-rice-nama/

adaptation such modern equipment. The economic crop zoning from MOAC has been introduced to define suitable areas for cultivating cash crops according to soil attributes and crop requirement criteria.

In the financial sector, Green Credit provided by the Bank for Agriculture and Agricultural Cooperatives (BAAC) offers loans to support farmers who adopt organic and sustainable agricultural practices. In addition, financial subsidy schemes for rice farmers are still implemented by the Ministry of Agriculture and Cooperatives on an annual basis. These schemes include the farmers' income guarantee scheme and rice price guarantee scheme. These schemes mainly focus on reducing farmers' financial hardship by guarantee farmers' income and stabilizing rice price for farmers without imposing any conditions to adopt new technologies and practices that would be able to improve productivity and provide better environment quality. Even though, these schemes would help solving farmers financial hardship especially in the short-run, they also have the effect of disincentivizing farmers to adopt new technology and practices that could increase productivity and improve environmental quality, which would improve and stabilize not only farmers' livelihoods but also generate benefits to public.

The information of policies and plans described above is applied to develop research questions in this study. In addition, they also provide information for scenarios development that focus on the different proportion of conventional and sustainable rice practices areas in this study. The current rice areas of GAP and megafarm project are set as the initial areas for SRP rice. After that the rate of expansion will be defined by three mains strategic targets based on the 20-year Agricultural and Cooperatives Strategy (2017-2036)[11], the 13th National Development Plan (2023-2027)[12], and the Thai Parliamentary targets relate to pesticide use regulation[13]. The details of scenario set up based on these policies and plans are explained in Part 2 below.

[11] www.oae.go.th/assets/portals/1/files/bapp/strategic2560-2579.pdf
[12] www.nesdc.go.th/main.php?filename=plan13
[13] https://bit.ly/2QOj46D

Part 2: Scope of the Assessment

1. Policy questions

Given the review of policies and plans regarding to improve agricultural sector toward sustainability described in Part 1 above, the research team has engaged the stakeholders in the process of consultation for determining the policy questions, which would be of relevance to the interests of stakeholders. The stakeholders include steering committee members, rice exporters, rice mills, rice farmers with sustainable practices (i.e. organic farmers and GAP farmers), and conventional rice farmers, as well as key resource persons, including SRP Secretariat, and GIZ etc (summary notes of stakeholders meetings are included in the Appendices).

On the basis of consultations with different stakeholders, including the Office for Natural Resources and Environmental Policy and Planning (ONEP), Steering Committee members and participants at a national workshop in Bangkok held in May 2022, farmers, millers and local officials in the Northeast of Thaialnd, as well as an analysis of existing policy gaps, the following focus topics and policy questions are agreed as the focus of the EU-PI-funded TEEBAgriFood assessment.

1.1 Pro-nature incentives for rice farmers – monetary and non-monetary

The well-being of farmers and sustainable livelihoods is a central consideration for Thai policy. The majority of rice farmers in Thailand is smallholders. They often manage plots of less than 2 hectares, and have high ongoing debt, and receive marginal cash incomes from rice farming. Many farmers have limited access to impartial technical advice, limited bargaining power with buyers, limited access to quality farm inputs, machinery and services, and are subject to price variability in unstable markets (millers do not always pay the guaranteed prices). Altogether, rice farmers have little material incentive, or effective means, to transition toward sustainable production practices in consideration of the public good and to reduce impacts upstream and downstream.

Commercial premiums for adoption of sustainable practices are not systematically available for rice farmers. Certification of compliance with internationally recognized standards, such as the SRP Standard, can nevertheless benefit farmers by opening up international market access and linkages with private sector buyers. Certification is in some cases linked to agricultural stimulus instruments such as the new BAAC green loans scheme[14], and programme support from the One Million Rai organic rice promotion program[15] subsidizing transition costs and promoting market links.

New incentives for encouraging good practices and discouraging detrimental practices need to be devised to reduce the ecological footprint of agriculture and food systems. The majority of financial support instruments distributed to Thai farmers currently are in the form of unconditional grants and assistance particularly to relieve financial hardship. The analysis will assess reorienting existing instruments, such as subsidy with crop productivity improvement to achieve not only furthering economic development, but also increasing the efficiency of production, boosting resilience to natural disasters, as well as achieving national environmental targets, to develop multiple benefits through a systems approach.

***Policy questions to be explored*:**

- How do small-scale farmers benefit from visible and invisible values due to adopting sustainable agricultural practice such as SRP standard? How do other stakeholders benefit from this adoption? Where could incentives be most equitably directed to encourage good practices?
- What would be the additional value and overall impact of adopting the Sustainable Rice Platform (SRP) Standard for Sustainable Rice Cultivation in Thailand in terms of impact on natural, human, social and produced capitals?
- What is the public sector return on investment (ROI) in promoting pro-nature production?
- What would be the socioeconomic dynamics/ systematic impacts of a change or reorientation of agricultural subsidies towards direct support of nature-positive production methods throughout the rice sector?

1.2 Valuing biological, and livelihoods of rice systems in the BGC economy

As Thailand aims to achieve a bio- circular and green economy (BCG economy), awareness remains limited of the existing and significant contribution of the country's biodiversity

[14] For more information of green credit, please visit https://www.baac.or.th/th/content-product.php?content_id=14262.
[15] For details of One Million Rai program, see http://www.nan.doae.go.th/scanbook%202560/v1870.1.pdf.

resources to Thailand's agricultural and wider economy and well-being. Thailand is a major exporter of diverse agricultural products. The wealth of Thailand's food culture and knowledge on traditional medicines are based on and only possible due to Thailand's significant plant biodiversity. Already built into Thailand's bio- circular and green economy, there is a large amount of existing knowledge and expertise. Rice farmers in Thailand as elsewhere in the region have developed skills in breeding a high diversity of rice genetic resources. Much of this heritage has been set aside in the past decades as farmers have responded to market signals and government promotion of high yielding and standardised rice varieties. However, seed selection and rice variety breeding skills are still maintained amongst sustainable farmers networks and are supporting the development of niche rice markets.

Thailand's rice production landscapes have different characteristics in different regions. In many areas, rice fields form part of a patchwork of farms and forest areas in a heterogenous landscape. Even in the more intensive lowland rice production areas served with irrigation, the rice landscape is often interspersed with trees and other border plants, which provide habitats for insect diversity, which links to farmland fertility, and to the rural economy. Rice plot bunds (raised soil walls to keep flood waters in place), and field borders more broadly, are very important spaces for wildlife that interact to enhance the rice ecosystem fertility and for other food plants encouraged by farmers. Maintaining agrobiodiversity in rice fields enhances rates of decomposition of organic material which is important for plant nutrition, as well as resilience to disease and climate change and mitigation.

Diverse rice landscapes, and rice farming communities therefore provide a solid foundation to develop a bio- circular green economy in the rice growing regions of the country. It also links into the increasing scientific interest globally in the multiple systemic linkages between soil health, plant health, animal health, human health, and planetary health.

***Policy questions to be explored*:**

- What is the long-term value of promoting biodiversity in rice landscapes and health impact for farmer and public?

2. Scenarios of land use change

To respond to the policy questions, alternative future scenarios will be modelled. The scenarios focus on the different proportions of rice area under conventional practice and sustainable rice practice. The plans and policies taken into account in the development of the scenarios for assessment include the current GAP project, GAP++ project, Megafarm project, and Thailand's long term 20-year Strategic Plan (2017-2036), and the related Master Plan for Agriculture that promotes the expansion of Thailand's sustainable products for both domestic and international markets. In addition to the policies and projects focused on agricultural goals, the scenario set up is also based on the National Master Plan on Climate Change (2015-2050) purposed by ONEP, the 13th National Development Plan (2023-2027), and Thai rice Nationally Appropriate Mitigation Action (Rice NAMA) that focus on reducing carbon emissions from agricultural activities. The timeframe for scenario analysis is 28 years, starting in 2022 and ending in 2050.

Four scenarios are presented below which differ in the proportion of conventional rice area and sustainable rice area. It is assumed that there will be no expansion or contraction of the rice growing area in the future to 2050. The projected conversion of land to sustainable rice practices are modelled exclusively in areas which are currently growing rice using conventional methods. The "sustainable rice" areas in the scenarios below are areas which will have been verified to have adopted all five management practices presented in the next section. Note that areas which adopt the more stringent requirements of organic rice farming such as Organic Thailand and IFOAM etc also qualify to be listed as "sustainable rice" areas below.

Scenario 1: Business as Usual (BAU)

The BAU assumes the steady continuation of the current rate of expansion of the GAP and GAP++ program. Since 2014, there has been an average increase of area adopting GAP and GAP++ practices of about 100,000 rai per year (16,000 ha). As of 2022, the area of adoption of "sustainable rice" practices is about 1 million rai (160,000 ha). It is assumed that this rate of expansion is continued so that an additional area of 500,000 rai will adopt sustainable rice practices in the Central and Northeastern regions every five years until 2050. The Business as Usual scenario projects that the "sustainable rice" area will reach a total of 3.8 million rai (608,000 ha) by 2050, accounting for 6.10 percent of the country's total rice production area.

Scenario 2: Moderate scenario

Conversion from conventional to sustainable rice practice improves but remains at a low rate.

This scenario assumes that the sustainable rice practice area grows steadily at a moderate rate of adoption following the **target set by the 20-year Agricultural and Cooperatives Strategy purposed by MOAC**, which requires an increase in sustainable agricultural area by about 650,000 rai per year. We assume that about 54 percent of this expansion occurs in rice farming resulting in an approximate increase of sustainable rice area by about 350,000 rai (56,000 ha) per year.

From the baseline of 1 million rai (160,000 ha) in 2022, the second scenario projects that the total area of sustainable rice will reach 10,800,000 rai (1,728,000 ha) by 2050, accounting for 17.3 percent of the country's total rice production area.

Scenario 3: Enhanced Scenario

Conversion from conventional to sustainable rice practice occurs at a medium rate.

This scenario envisions a significantly enhanced ambition to promote sustainable agriculture in Thailand based on the **target of 13th National Development Plan** starting in 2023, which targets to increase sustainable agricultural area by about 2 million rai per year (320,000 ha). We assume that about half of this expansion occurs in rice farming. From the baseline of 1 million rai (160,000 ha) in 2022, the additional area of sustainable rice practice in this scenario is assumed to rise on average by 1,000,000 rai (160,000 ha) per year. Under this scenario, by 2050, the total sustainable rice practice area would reach 29,000,000 rai (4,640,000 ha), accounting for 46.5 percent of the country's total rice production area.

Scenario 4: Transformational Scenario

Conversion from conventional to sustainable rice practice occurs at a high rate.

This scenario represents the level of sustainable rice practice adoption that is **consistent with the decision of the Thai parliament in 2018, which takes account the 2030 Sustainable Development Goals**, and set a target of 149 million rai or 100% of Thai agricultural land to be cultivated using sustainable agriculture practices by 2030.

Approximately half of Thailand is dedicated to rice, so this target would require that approximately 68,000,000 rai of land adopt sustainable rice practices by 2030.

However, it is recognized by many stakeholders that this goal is very ambitious and may be difficult to achieve, especially in the short run. There is a large gap between current levels of adoption and proposed targets in 8 years' time. There are also many structural barriers to change, including high levels of farmer indebtedness, income poverty, and risk aversion, incomplete market development or sustainable agricultural products both nationally and internationally, limited rural infrastructure for water management, and for the processing of sustainable agricultural products, unequal access to information and resources. These barriers serve to obscure the long-term impacts of unsustainable practices etc that fall directly on farmers, the public and on the continuance of agriculture production over time

For this scenario, we assume the government undertake extensive efforts to promote sustainable rice practice resulting in an increase of sustainable rice area in Central and Northeast region on average by 2,000,000 rai (320,000 ha) per year until 2045.

Under this scenario, the total sustainable rice practice area would reach 47,000,000 rai (7,520,000 ha), accounting for 75.28 percent of the country's total rice production area by 2045 and remain constant to 2050.

Table 2: Summary projected expansion of sustainable rice practice in alternative scenarios

Year	BAU		S2		S3		S4	
	Million Rai	Sustainable / Total rice area (%)	Million Rai	Sustainable / Total rice area (%)	Million Rai	Sustainable / Total rice area (%)	Million Rai	Sustainable / Total rice area (%)
2022	1	1.60	1	1.60	1	1.60	1	1.60
2030	1.8	2.88	2.05	6.09	4	14.41	17	27.23
2035	2.3	3.68	5.55	8.89	9	22.42	27	43.24
2040	2.8	4.48	7.3	11.69	14	30.43	37	59.26
2045	3.3	5.29	9.05	14.49	24	38.44	47	75.28
2050	3.8	6.10	10.8	17.3	29	46.5	47	75.28

3. Definitions and parameters

To inform the policy questions presented above, the research team will present an analysis of the scenarios above within the following scope for research and biophysical modelling:

Defining the geographical scope

The scope of this assessment will include rice cultivation area in Central and Northeast regions of Thailand. Together, the rice cultivation area of these two regions covers more than 80 percent of rice cultivation area in Thailand.

In the Central region, the project will focus on the Central plains area, in the following 5 provinces Suphanburi, Phra Nakornsri Ayuthaya, Chainat, Ang Thong, and Pathum Thani, where the GAP++ Standard is being introduced. In the Northeastern region, the project will focus on 7 of the 10 provinces with the largest rice production areas: Khon Kaen, Sakon Nakorn, Udon Thani, Ubon Ratchathani, Roi-et, Nakorn Ratchasrima, and Surin. In the Northeast, the GAP++ Standard is being introduced in Ubon Ratchatani.

Defining the scope of sustainable rice management practices

The sustainable rice cultivation activities promoted by the SRP Standard, which are identified as having an impact on "biodiversity" and "greenhouse gas emissions" are the focus of this analysis. These comprise the following requirements (for further details, see Appendix 3):

SRP Standard Requirements

6 (ensuring no land conversion and enhancing site-specific biodiversity),

7 (ensuring no invasive species are introduced),

8 (recommending land leveling),

10 (recommending water management in rainfed and irrigated systems),

14 (ensuring delay of drainage to avoid agrichemical contamination),

15 (recommending efficient and site-specific use of organic and inorganic fertilisers),

16 (encouraging organic fertilizer),

17 (ensuring no counterfeit inorganic fertilizers are used),

18 (encouraging integrated pest management)

24 and 25 (ensuring there is no burning of residues (rice straw and rice stubble))

The management practices promoted by the SRP have many details and the scoring system allows for contingent adoption of certain practices. The following approach has been taken by the research team for the purposes of this assessment to simplify the scope of management practices to be included in the definition of sustainable rice production. Five specific practices have been selected to represent the essential compliance requirements from the above list. Each of these practices are described below.

1. Water Management

Sustainable rice farmers are assumed to time the establishment of their rice crop according to the local climate, and to maintain strong bunds to allow for effective water management.

In the irrigated areas, areas defined as "sustainable rice areas" will be assumed to be managed with the Alternate Wetting and Drying (AWD) technique. AWD is a water management practice where irrigation is applied at intermittent intervals resulting in alternating wet and dry soil conditions. This technique is promoted as a means to reduce both water consumption and GHG emissions from rice cultivation, without yield penalty. In this study, farmers practicing AWD are assumed to have one "dry-down event" that is, a mid-season drainage of the rice field that lasts for 7 days.

In the rainfed areas, farmers have limited control over flooding conditions, making it difficult to comply with any pre-defined AWD regime. Therefore, in the rainfed areas, "sustainable rice" areas will be assumed to be continuously flooded for 100 percent of the period of cultivation before harvest. In these areas, it is assumed that farmers adopt direct broadcast seeding (*na waan*) rather than transplanting seedlings from a nursery (*na dam)*.

Water management will have a differential impact on GHG emissions in the areas studied. It will also have a differential impact on the amount of water available for other uses in the irrigated areas compared to conventional rice farming.

2. Nutrient management

Sustainable rice farmers are assumed to use fertilizer in a sustainable, efficient and site-specific way. All sustainable rice farmers are assumed to apply fertilizer according to plant needs, locally adapted recommendations, and label instructions, both in terms of timing and quantity.

Organic fertilizers are applied where locally available, and are assumed to be left to decompose before the fields are flooded. Inorganic fertilizers are used to supplement organic fertilizers, and are assumed to be from a registered source.

The efficiency of fertilizer is expected to have an impact on rice yield, cost of production, water quality and GHG emissions.

3. Natural systems of soil fertility enhancement

Rice farmers who apply sustainable rice practice in Central and Northeast regions are also assumed to apply natural systems of soil fertility enhancement. For the purposes of this assessment, the practice which is assumed to be adopted by sustainable rice farmers in the areas studied, is cover cropping.

Rice farmers in the rainfed areas in both regions who apply sustainable rice practices are assumed to plant sunn hemp (*Por Tueng*) in the fields after the rice harvest. This crop is not grown for market, but to enhance ecosystem services. Sunn hemp is a nitrogen fixing plant that is not especially prone to pest attack, and is effective at blocking out weeds. It can be harvested for use as cattle feed. Growing sunn hemp after rice is recommended to improve soil properties, reduce soil erosion, conserve soil water, and recycle plant nutrients back into the soil. All of these would impact rice yields, costs of rice production, GHG emissions, and soil carbon sequestration.

4. Integrated Pest Management

Sustainable rice farmers are assumed to use preventative pest control methods before considering the use of chemical pesticides. It is assumed that pesticides are used only if other methods are not effective on their own and they are carefully targeted to limit the area of exposure. Pesticide is assumed to be government approved, applied according to product label, follows specified preharvest interval, and does not exceed the dosage for worker and food safety. Broad spectrum insecticides are not used at all within the first 40 days after the rice crop is planted.

Appropriately and carefully applying chemical pesticides will have an impact on rice yields, rice production costs, and on aquatic, aerial and terrestrial biodiversity, as well as farmers' health.[16]

5. Rice straw and stubble management

Sustainable rice practice requires that there is no burning of either rice straw or any rice stubble left in the field. For the purposes of this study, it is also assumed that rice residues left in the field are allowed to decompose for at least 2 weeks before the field is tilled or flooded.

This practice will have an impact on the reduction of GHG emissions, soil carbon sequestration, and rice yield when compared to conventional rice practice.

Table 3 presents a summary of the different management practices to be assessed in the conventional rice area and sustainable rice area as defined above.

Table 3. Parameters / assumptions for analysis for each scenario

	Central region (irrigated systems)			NE region (rainfed systems)		
SRP requirement	Conventional rice production	Sustainable rice production	Post-rice crop	Conventional rice production	Sustainable rice production	Post-rice crop
No of crops per year	2-3	2	1	1	1	1
Water Management	Continuous flooding	AWD is practiced		Continuous flooding	Continuous flooding	
Nutrient management	Inorganic fertilizer is applied at current rates	Mix of fertilizers are used appro-priately		Inorganic fertilizer is applied at current rates	Mix of fertilizers are used appro-priately	

[16] For minimum compliance requirements see SRP Standard Version 2.1 January 2020 at sustainablerice.org

Integrated Pest Management	Average pesticide uses at current rates of application	No insecticide for first 40 days. Reduced herbicide use	No pesticides	Average pesticide uses at current rates of application	No insecticide for first 40 days. Reduced herbicide use	No pesticides
Rice straw and stubble management	21% of rice residue is burned	No straw or stubble is burned		21% of rice residue is burned	No straw or stubble is burned	

Defining the temporal scope

The timeline of projection on impacts on natural capital, human capital, and social capital according to expansion of sustainable rice practice is proposed from 2022-2050. Table 3 presents the expansion of sustainable rice area for each scenario between 2022-2050[17].

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4. Expected research outputs

- Cost/ Benefit analysis of land use change scenarios relative to Business as Usual, including:

  Production Dimension

  - Change in total rice production output (tonnes / per rai / per region / per year).
    - Change in rice outputs (tonnes per rice variety)
    - Change in pesticide use (tonnes),
    - Change in fertilizer use (tonnes),
    - Change in irrigation demand m^3 (USD)
  - Valuation of losses and gains
    - Change in total rice value to farmers (USD per tonne /per household / per rai/ per region/ per year).
    - Change in rice values (USD) by rice variety
    - Change in production costs (savings in pesticide, fertilizer, increased expenditure in machinery/ irrigation, processing etc) (USD)
    - Changes in government investment budgets per rai/per rice farming household (USD)

[17] The projected expansion rate of stainable rice area may be subject to change when the spatial modelling is employed.

Environmental Dimension

- Changes in ecosystem service provisioning due to change in rice management practices over time.
  - Changes in carbon emissions from rice (CO_2 eq),
  - Changes in air pollution from rice residue burning (PM 2.5)
  - Changes in water consumption of rice in irrigated area (cu.m),
  - Changes in pollution of water bodies
  - Changes in insect species diversity (% change in biodiversity indices)
  - Changes in soil organic carbon sequestration (SOC)
  - Changes in soil moisture retention
- Valuation of losses and gains in ecosystem services
  - Change in value of carbon emissions reductions from rice (at local and international projected market prices – to include the projected increase in the social cost of carbon) (USD).
  - Change in nutrient use efficiency (reduction in overuse of inorganic fertilizer) (USD)
  - Change in value water resources (USD)
  - Change in value of alternative uses for rice straw (eg As soil enhancement) (USD)

Health dimension

- Change in human capital indicators due to change in rice farming practices over time.
  - Reduction in fatalities (Number)
- Valuation of losses and gains of human capital
  - Change in health-related economic outcomes (change in gross provincial productivity (GPP) related to exposure to PM2.5 from rice burning) (USD)
  - Change in health expenditure (eg farmer actual expenditure on minor health symptoms of pesticide exposure, change in public health budgets from long term exposure to PM2.5 from rice burning, long term exposure to pesticide poisoning) (USD)

    - Valuation of health risk reduction (revealed preference) by rice farmers (USD)

- Qualitative and gender-differentiated analysis of changes in social capital

  Changes in the social capital dimension will not be included in the scenario analysis, as projected changes are not assessed with reference to land use change. A qualitative discussion of differences identified in social development of different rice farming groups (conventional vs sustainable rice farming households) will be outlined in the results document.

- Regional level maps of changes in biodiversity, water provisioning, water quality, and carbon storage, with projections into the future according to each scenario from 2022 to 2050

- Policy recommendations based on research findings
  Including scenario analysis, key messages, theory of change and policy roadmap with five yearly milestones.

- A national workshop will be held in 2023 to discuss the research findings and seek inputs to develop a theory of change and feed into policy mainstreaming.

5. Expected research outcomes

- Opportunities identified in consultation with key stakeholders in public and private sector for value addition in the rice value chain that support the national economy, rural livelihoods and the environment.

- New areas for research and development suggested for sustainable rice practices adoption.

- Recommendations of policy incentives or investments for improved value addition in the rice value chain that support the national economy, rural livelihoods and the environment.

Part 3: Methodology

Change in land-use is a major driver of environmental change. Land-use change modeling highlights how and where the conventional rice areas are converted to sustainable rice for each scenario. The results from land-use change modeling are used to spatially analyze the effects of land-use changes on various measures. The spatial analysis at the landscape level generates results at a regional scale and considers landscape configuration (for example, habitat fragmentation) and context (for example, proximity to landscape features such as watercourses), as these are key factors in determining impacts on the relevant ecosystem services and biodiversity.

1. Method of Spatial analysis

The spatial analysis proposed in this study has two main components.

1. Land use change modelling, which aims to analyses changes of land use, in particular where conversion to sustainable rice cultivation is projected to take place.
2. The integration of household survey data on farmers' adoption of sustainable rice practices.

1.1 Land use Change Modelling

A promising precise method for understanding past land use, types of changes to be estimated, and the forces and developments driving future changes is land-use change assessment.

The study aims to examine the temporal and spatial land use dynamics of the past and predict the future using Land Change Modeler (LCM). This study applies the LCM for rice production to determine the land conversion of rice production in the future. The study will generate the results at the landscape level, considering the main key factors to configure the impacts on ecosystem services and biodiversity.

The conceptual framework of LCM to assess the change of land-use is presented in figure 3. Land cover is mapped at two-time stamps (referred to as T1 and T2) in LCM, and the patterns and processes of change are estimated and used for model parameterization/calibration. The LCM analyzes changes in land use between two time stamps (T1 and T2) for which data exists in the past, and creates transition potential maps using Multi-layer Perceptron (MLP) with explanatory spatial variables. A Markov Chain Analysis assigns the probability of change determined by projecting historical change into the future, along with transition potential maps, presenting a land-use scenario for current period (referred to as T3). The T1 and T2 of land use, in particular the agricultural land, including the sustainable rice cultivation area, will be validated before being used in prediction for any given future period (T4).

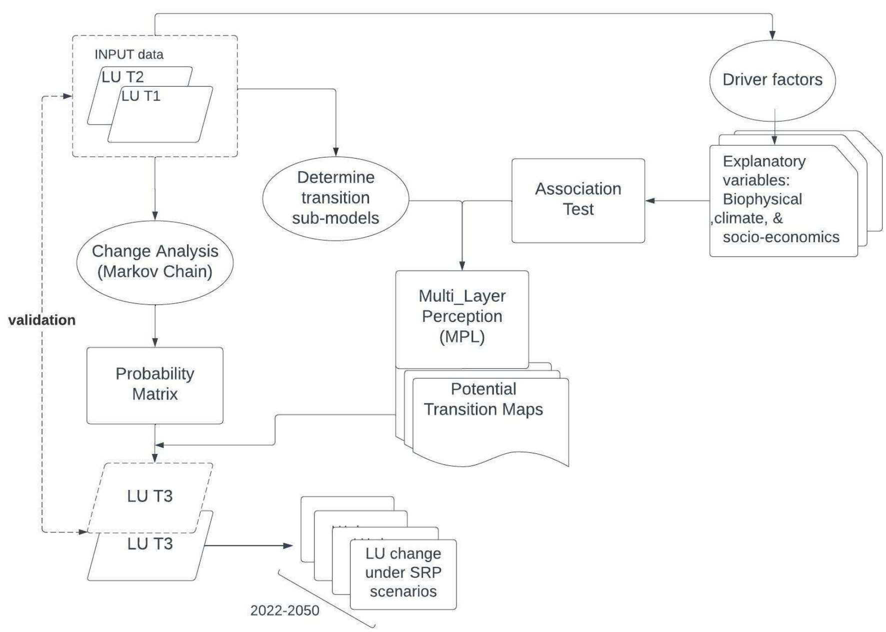

Figure 3. LCM method to predict land-use change

The LCM will be processed using IDRISI-Terrset[18]. This software provides tools for the assessment and projection of land-use change. Several factors contribute to the conversion of agricultural land and its surroundings, including population growth, urbanization, regional development. Previous studies have shown that land-use is changing, mainly from agricultural to built-up land (Ambarwulan & Munibah, 2013). The changes of agricultural land use reflect socio-economic driving forces such as land-use policy (Mottet et al., 2006). The presence of rice fields

[18] v.18.31 Clark Labs, Clark University, Worcester, MA, USA.
Eastman, J.R. IDRISI Terrset Manual; Clark Labs-Clark University: Worcester, MA, USA, 2016.

is intrinsically linked to population growth. The pressure of providing space for a region's population will increase as the region's population grows (Dwinanto & Sudadi, 2016). Table 4 presents a set of driver variables of primary change which will be applied in the LCM.

Table 4. Data for the LCM analysis

Variables	Description	Sources
Administrative boundary	A vector of administrative limits of provinces and municipalities	Department of Public Works and Town & Country Planning, Ministry of Interior
Land-use	Land use maps (2013 and 2021)	Land Development Department, MoAC
Land suitability	Land suitability for rice agriculture	Land Development Department, MoAC
Organic rice paddy	Land use for organic rice cultivation (available years)	Rice Department, MoAC
Mega rice farm paddy	Rice paddy fields area under the Mega rice farm project	DOAE, MoAC
Rice paddy fields	Rice cultivation area suffered from drought (under the rice department observation project in 2021)	Rice Department, MoAC
GAP Rice paddy	The Good Agricultural Practice for rice (GAP) certified paddy fields in 2013-2017.	Rice Department, MoAC
Slope	A slope in degree calculated from Digital Elevation Model (DEM)	Author calculation
Elevation	Digital Elevation Model > Shuttle Radar Topography Mission (SRTM) 30m. Elevation, aspect	Digital Chart of the World
Road	Thailand road network, including all types	GISTDA Thailand
Distance to urban area	Euclidean distance from LU type U1, U2, and U3 defined by LDD	GISTDA Thailand
Irrigation zone	Irrigation types and boundary	Royal irrigation department, MoAC

Climate data	Maximum, minimum, average temperature, and average daily precipitation sum using RCP4.5 emission scenarios.	Center of Regional Climate Change and Renewable Energy, Ramkhamhaeng University Thailand[19]

This model aims to investigate the variation of land-use under different future scenarios of rice production. The land-use change predictive scenarios are shaped by the potential changes of rice production area from conventional rice to sustainable rice production from 2022 to 2050. We will simulate the land-use change to reflect all scenarios.

As outlined in Part 2 above, the "sustainable rice area" is defined as where rice fields are cultivated with the sustainable management practices defined in this study, while the "conventional rice area" is where none of the management practices above are applied.

For expediency, in developing a baseline for modelling, some of the areas identified as having already adopted sustainable rice practices, may not have adopted all SRP management practices outlined above, but in these areas, at least one farming household has registered in the Mega Rice Farm project for rice cultivation.

The spatial variation of land-use presented in scenarios reflects government targets and relevant policies. The expansion of rice area for potential future changes under scenarios will be considered to address the associated uncertainties of different sectors in the study. We assume that the variation of government promotion associated with rice production has the potential to reflect the change in rice area. This means that the government-promoted projects will be used to represent the sustainable rice area in this study.

Changes at the landscape scale also can link the uncertainties of biodiversity and ecosystem services so that the comparative impacts can be made visible to different stakeholders through the land change modeling.

The projection of land-use change is based on policies as discussed in Part 2 - Scope of the Analysis above. According to our assumptions, the area of rice land use is controlled, so that only areas that are deemed "suitable" for the cultivation of rice as defined by Land Development Department, will be considered capable of conversion to sustainable rice area in our projections.

[19] http://www.rucore.ru.ac.th/

The available spatial data will be collected and used to visualize the current situation of the sustainable rice cultivation in Thailand. For instance, maps of rice production under the Good Agricultural Practice (GAP) for rice production will be used. The geographic data of GAP rice production (see red dots in Figure 4 below) will be used to present one location under the sustainable rice practice in this study. The top left panel in Figure 3 shows the Thailand suitability for rice production classified into "suitability" levels, ranging from highly suitable (S1) to unsuitable for growing rice (N). As can be seen in figure 3 (right and bottom panels), GAP rice production areas in 2016–2017 are clustered in the central and northeastern regions, the study area for this assessment (blue polygons). Similarly, the mega rice farms (purple dots) are concentrated in the same areas.

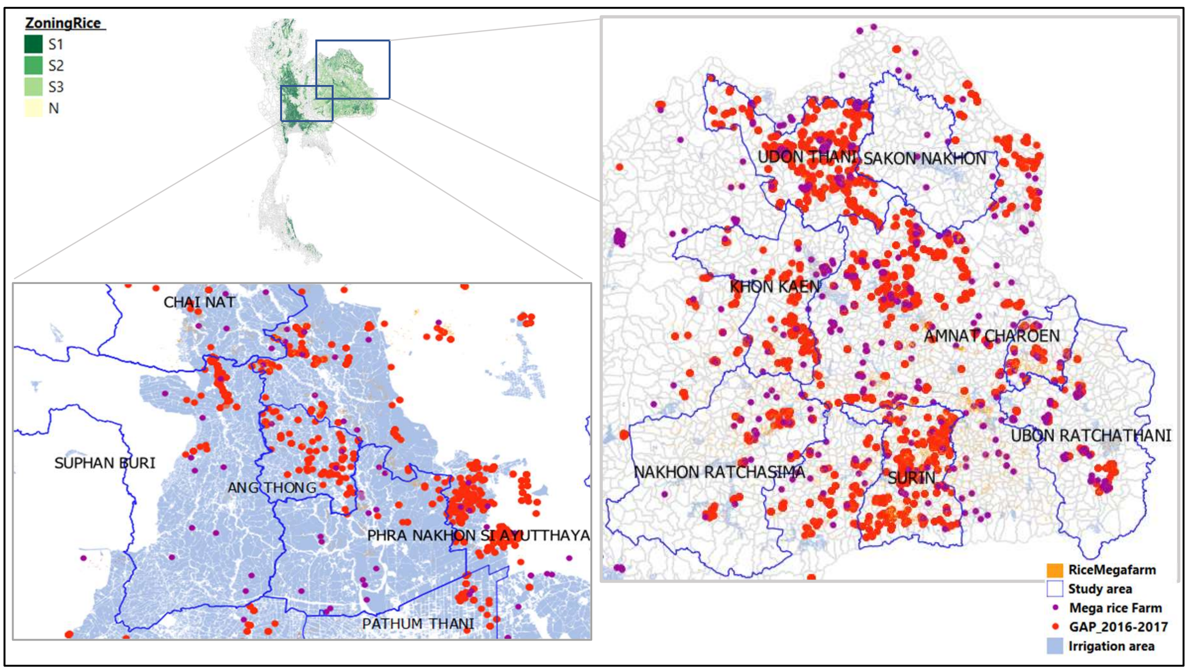

Figure 4. Maps of rice production under GAP program and mega rice farm project
(Sources: Rice department, MoAC).

1.2 Spatial analysis integrated with data on farmer adoption of sustainable rice practices.

The second component of spatial analysis is developed to bridge the gap between the land use change model and farmers' adoption of sustainable rice practice. This will incorporate household survey data and the relevant spatial data into the analysis. A farmer's choice is influenced by the qualities of the farmland used for rice cultivation. Growing rice requires a decent amount of land area to achieve sufficient yield. The farmers choices will have a significant impact on how the land is used. The analysis intends to examine relationships between four parameters, including household characteristics, the farmer's perspectives on sustainable rice practice, field features, and the farmers' geographic location, and how this influences their adoption of sustainable rice practices (Fig 5.). The results of this section will be used to further present the spatial dependency at the study site and landscape level.

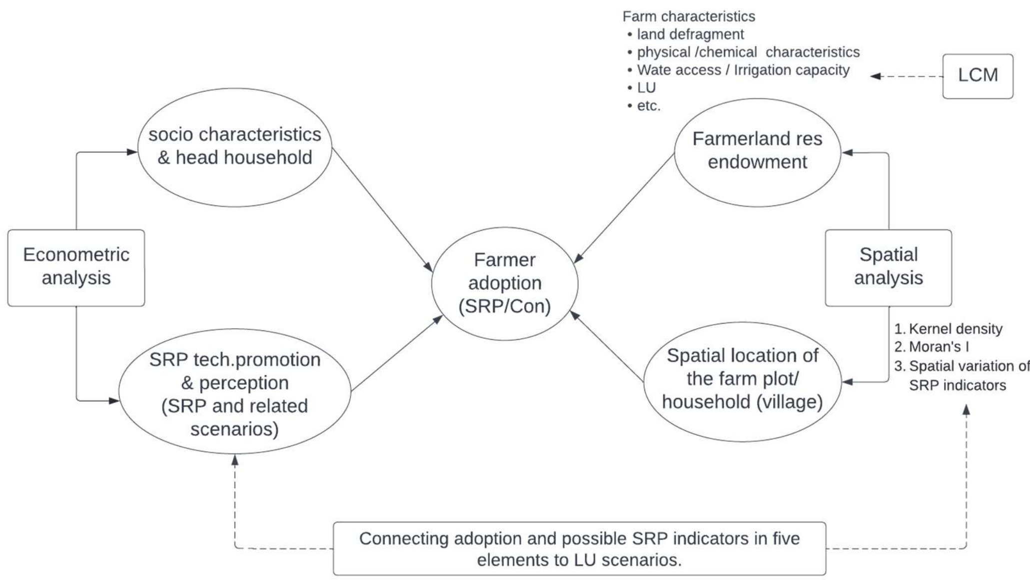

Figure 5. Conceptual framework for analysis of farmer adoption of SRP

2. Method of Biophysical Modelling

The land use area changes under each scenario are linked to measurable changes not only to output and revenues from rice (produced capital dimension) but also capital stocks related to two additional dimensions: natural capital, and human capital.

As described in the TEEBAgriFood framework, the outcomes of agricultural production, processing, distribution, and consumption can be understood as changes in natural, human, social, and produced capital. Outcomes related to natural capital stocks that are covered in this study include changes to biodiversity, GHG emissions, air pollution, and water footprint. Outcomes in terms of changes in human capital relate to changes in health of both farmers and the general public will be also explored.

TEEBAgriFood analysis in Thailand uses a scenario modelling approach to examine the potential future impacts of land-use changes as a result of current sustainable rice expansion. Impacts are assessed at the landscape level in terms of changes in rice-field biodiversity, the emission of greenhouse gases, air pollution, water footprint, and the health impacts of chemical pesticides. The plan of study and methodologies applied for each measure are as follows.

2.1 Greenhouse gas emissions and soil carbon sequestration

2.1.1 Greenhouse gas emissions from rice cultivation

GHG emissions is an indicator used to evaluate the performance of both the Good Agricultural Practices (GAP) Standard and the Sustainable Rice Platform (SRP) Standard. Under both Standards, sustainable rice practice is assumed to provide a framework for advanced farming practices, leading to higher net profits, increased yields, enhanced food safety, and lower GHG emissions.

The long-term observation of CH_4 and N_2O emissions, grain yields and SOC stocks is difficult due to spatial differences in environmental factors. Therefore, a modelling approach is used to simulate the long-term variation of rice grain yield, SOC sequestration, and GHG emissions under different environmental factors and field management practices.

2.1.2 DNDC model, data sources and key assumptions

The Denitrification-Decomposition (DNDC) model is a computer simulation that has been developed for predicting carbon and nitrogen cycling in agroecosystems (Li et al., 1994). The DNDC has well simulated in long-term SOC dynamics and GHG emissions and other related variables such as crop yields from rice cultivation (Shirato, 2005; Babu et al., 2006; Chen et al., 2016; Cha-un et al., 2015; Ch-un et al., 2017; Naher et al., 2020; Cha-un et al., 2021). This study will use the DNDC model to investigate the emissions of CH_4 and N_2O, grain yields, and SOC stocks under different rice management practices in the representative provinces in the Northeast and Central regions of Thailand along the long-term (2022-2050) simulation.

The Denitrification-Decomposition (DNDC) model can be used for predicting crop growth, soil temperature and moisture regimes, soil carbon dynamics, nitrogen leaching, and emissions of trace gases such as carbon dioxide (CO_2), nitrous oxide (N_2O) and methane (CH_4) (Institute for the Study of Earth, Oceans, and Space, University of New Hampshire, 2017).

Field observation data from several published papers in a Thai rice field experiment will be used to calibrate and validate the SOC stock, rice grain yield, and emissions of CH_4 and N_2O in order to examine the reliability of model (see table 5 below).

In line with the IPCC guidelines for GHG inventories of emissions from crop cultivation, flows of CO_2 released from cropping systems are considered to be generally balanced with the sequestration of CO2 through vegetative growth stages, and thus are not measured in this analysis.

Table 5. Thai rice field experiment and parameters for model validation

Region	Province	Parameter	Reference
Central	Ratchaburi	SOC stock, grain yield, CH_4, N_2O	Cha-un *et al*., 2017
	Prachinburi	grain yield, CH_4, N_2O	Chidthaisong, *et al*., 2018
	Ratchaburi	SOC stock, grain yield, CH_4, N_2O	Sriphirom *et al*., 2020
	Pathum Thani	grain yield, CH_4, N_2O	Ruensuk *et al*., 2021
	Ang Thong	grain yield, CH_4, N_2O	Ruensuk *et al*., 2021
	Chai Nat	grain yield, CH_4, N_2O	Ruensuk *et al*., 2021
Northeastern	Khon Kaen	grain yield, CH_4	Saenjan *et al*, 2006 Thammasom *et al*., 2016
	Sakon Nakhon	grain yield, CH_4, N_2O	Ruensuk *et al*., 2021
	Ubon Ratchathani	CH_4	Rossopa *et al*., 2013

Grain yield assumptions: Rice varieties included in the assessment

In the main season, over 60 percent of Thailand's rice cultivation area is located in the Northeast (NE). The glutinous rice variety (RD6) is mainly cultivated in the upper part of the Northeast (U-NE) (64 percent), whereas Hom Mali or fragrant varieties of rice (KDML 105, RD15) (95 percent) are cultivated in the lower part of the Northeast (L-NE) (see Figure 6).

In the Central (C) region, the availability of water from irrigation networks makes it possible to produce at least two crops of rice per year. This region produces what is referred to in trade statistics as "white rice". The common varieties of white rice from this region are Pathum Thani 1 (PTT 1), Suphan Buri 1 (SPR 1), and Chainat 1 (CNT 1) (Varinruk, 2017).

Five provinces in Central region and seven provinces in Northeast region have been selected to represent the studied rice areas in Thailand (see Table 6). In each of these provinces, one rice variety is selected to represent the production of rice in that province. For example, the dominant rice variety in Ubon Ratchathani is Hom Mali. Therefore, Hom Mali will be the representative rice in Ubon Ratchathani. The variety of rice relates to the yield which is projected through the modelling.

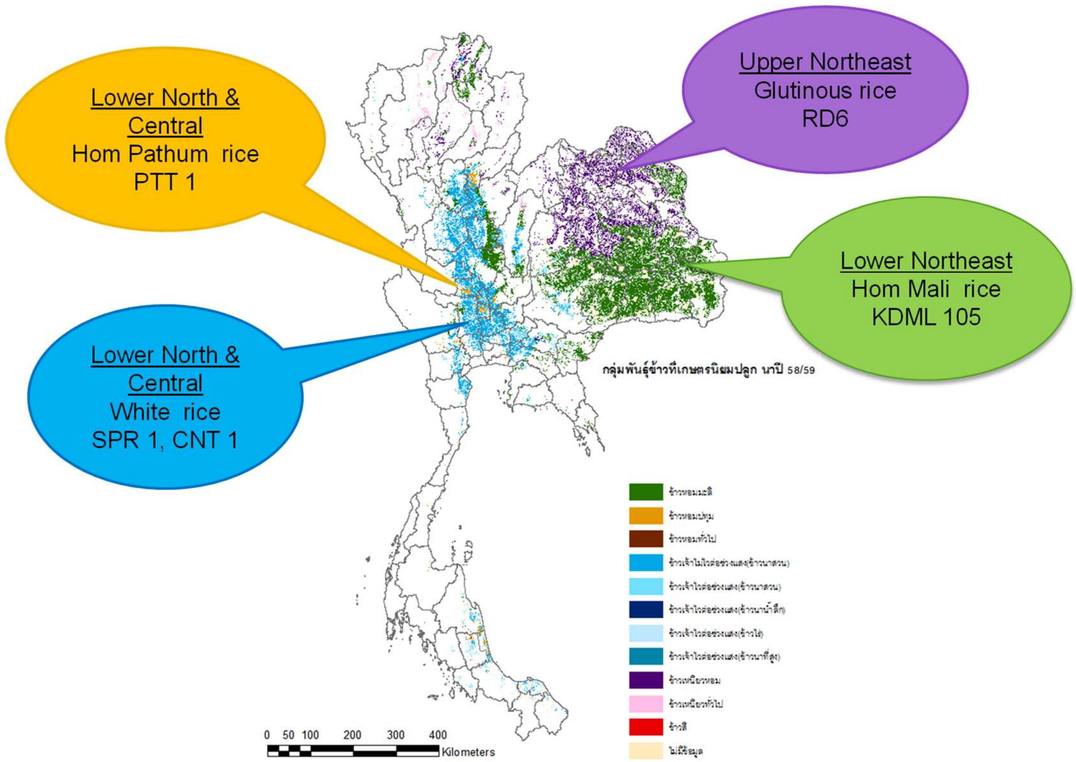

Figure 6. Rice varieties in different sub-ecosystems
(DOAE, 2017; Varinruk, 2017)

Table 6. Rice varieties taken to be representative of provinces studied in Thailand

No.	Region	Province	Representative rice variety
1	Central	Suphanburi	
2	Central	Phranakornsri Ayuthaya	
3	Central	Chainat	tbc
4	Central	Angthong	
5	Central	Pathumthani	
1	Northeast	Khon Kaen	Glutinous rice (RD6)
2	Northeast	Sakon Nakorn	Glutinous rice (RD6)
3	Northeast	Udon Thani	Glutinous rice (RD6)
4	Northeast	Ubon Ratchathani	Hom Mali (KDML 105)
5	Northeast	Roi - et	Hom Mali (KDML 105)
6	Northeast	Nakorn Ratchasrima	Hom Mali (KDML 105)
7	Northeast	Surin	Hom Mali (KDML 105)

Climate data assumptions: Representative concentration pathways (RCP)

The climate data from 1991-2021 are obtained from the observation stations of Thai Meteorological Department and the climate data for the future simulation (2022-2050) obtained from EC-EARTH model, simulation version RegCM4.7, assuming the emissions scenario RCP 4.5 (Ramkhamhaeng University Center of Regional Climate Change and Renewable Energy: RU-CORE, 2020). RCP 4.5 is an intermediate stabilization scenario that assumes that climate policies are invoked to achieve the goal of limiting emissions, concentrations, and radiative forcing.

Soil data assumptions: Land Development Data soil series

The soil data of each site are compiled from the database of the Land Development Department of Thailand. The crop calendar and field management practices (Cha-un *et al*., 2021) for each site were compiled from the government published reports, supplemented with data obtained from the Rice Department (Varinruk, 2017; RD, 2019) and the Office of Agricultural Economics, Ministry of Agriculture and Cooperatives (OAE, 2019).

Field management assumptions

The scenarios of rice field management practices with three cropping systems, two crop residue management systems, two regimes of fertilizer use and two water management systems in each study site provided 48 situations of model simulations (see Table 2). The simulated results from the study sites will be averaged for each region. Then, the average results of each region are used to estimate the GHG emissions, SOC stock, and rice yield in the whole region for each scenario.

2.1.2 Post-harvest GHG from rice residue burning

Rice residue burning is a significant source of air pollution including Greenhouse Gases. Paddy fields are mostly located in the central and northeastern regions of Thailand, which has the peak season of residue burning around January to April as shown in the total particulate matter emission maps in Figure 7 (Garivait, S., Bonnet, S., & Kamnoed, O., 2008). Residue burning is prohibited in sustainable rice practices promoted by Organic Thailand, GAP++ and the SRP Standard.

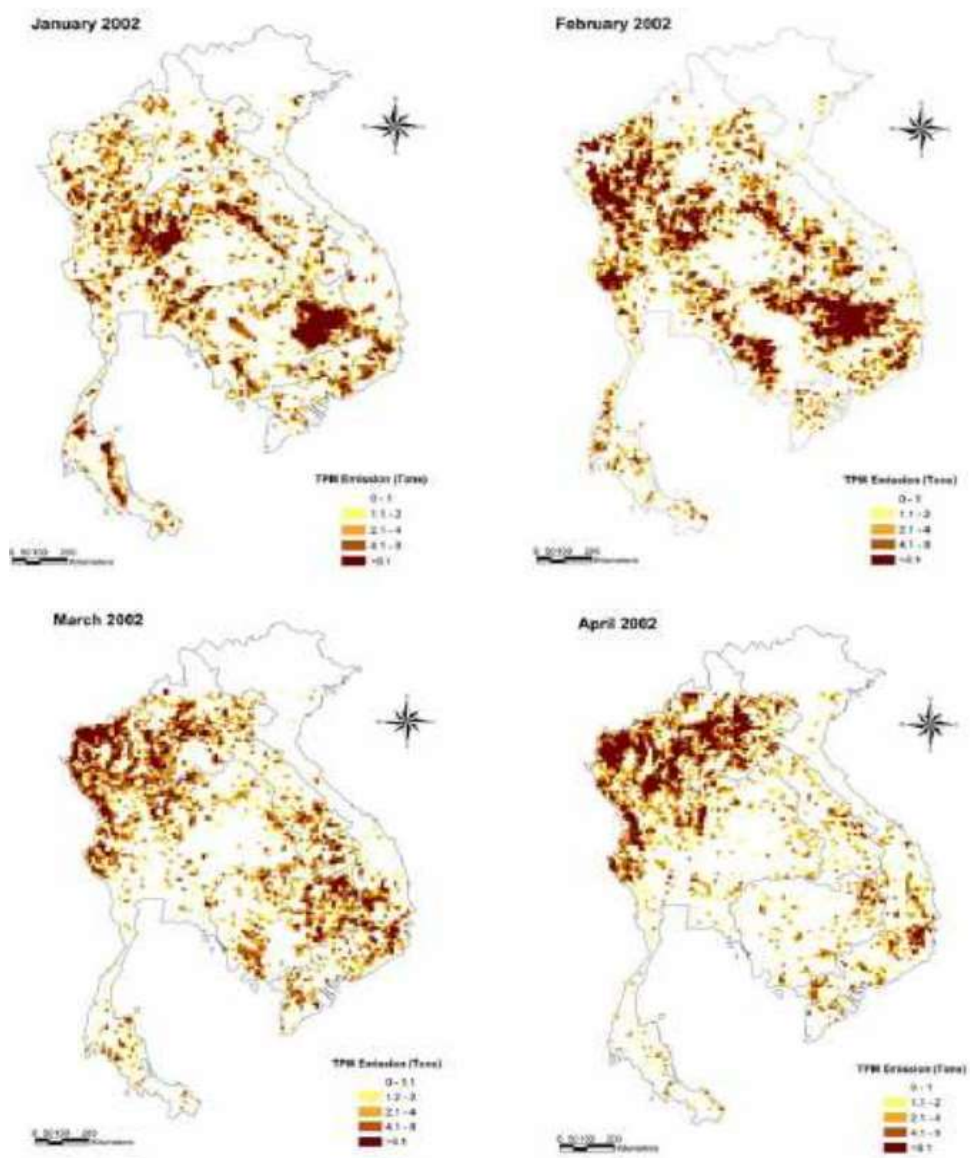

Figure 7. Monthly total particulate matter emission from rice residue burning in 2002
Source: Garivait, S., Bonnet, S., & Kamnoed, O., 2008

Greenhouse gas (GHG) emissions from rice straw burning in this analysis will focus on emissions of Methane (CH_4) and Nitrogen oxides (NO_x). GHG emissions from rice stubble burning are calculated based on chapter 2 of 2006 IPCC guidelines for national greenhouse gas inventories. CO_2 emissions from rice burning are excluded from these calculations (Eggleston, H. S., et al., 2006),[20].

The method applied for calculating the level of GHG emissions from rice residue burning, is explained in the following section. The same method is used to calculate PM2.5 emissions from rice residue burning. The PM2.5 data will be applied in the health costs analysis later in this assessment.

2.1.2.1 Method for calculation of emissions of GHG and PM 2.5 from rice residue burning

The emission of air pollutants from rice residue burning have been analyzed in published literature on Thailand and the Greater Mekong Subregion (Junpen, et al., 2018 and Garivait, S., Bonnet, S., & Kamnoed, O., 2008). The pollutant emissions are estimated based on the fraction of rice residue subjected to open burning, the amount of residue in the field, and rice cultivation area.

The calculation starts with the estimation of the mass of burned dry matter, which is computed by average amount of rice residue, the fraction of burned rice residue, and rice cultivation area. Our model will apply variables provided in the reviewed literatures; however, some variables could be updated based on results from the household survey on average rice straw utilization. After that, the emission factor of the air pollutants in each element will be applied to calculate the air pollutant emissions. A number of studies have measured the emission factors. This study transfers selected values from Junpen, et al., (2018), based on nine emissions: Carbon monoxide (CO), Carbon dioxide (CO_2), Methane (CH_4), Nitrogen oxides (NO_x), Sulfur dioxide (SO_2), Black carbon (BC), Organic carbon (OC), PM10, and PM2.5. The value of selected emission factors is shown in table 7.

[20] other negative impacts from rice straw burning include fine particulate emissions, in particular PM 2.5. This has important impacts on public health. The method to be applied for analysing this in terms of health cost will be presented in the next section.

Only the conventional rice area will be considered to be subject to open burning of rice residues. This is because residue burning in the organic and sustainable rice practice is prohibited. The result will provide the amount of GHG emissions as well as particulate matter that also generate global warming and health impact.

Table 7. Value of emission factors from rice residue burning

Gases/particulate matter	Emission factor (EF) (grams per kilogram of burned dry matter)	Included in the assessment
CO2	1,177	n/a
CO	93	n/a
CH4	9.6	GHG emissions
NOx	0.49	GHG emissions
SO2	0.51	n/a
BC	0.53	n/a
OC	3.1	n/a
PM2.5	8.3	Health impact
PM10	9.4	n/a

Source: Junpen, et al., (2018)

2.2 Water use in rice cultivation: water supply, water quality and water footprint

Unlike many food crops, rice plants tolerate water logging. In the climate of Southeast Asia, with heavy monsoon rains and seasonal flooding, rice cultivation thrives. This adaptation of nature allows rice to outcompete weeds benefit, such that water provides an ecosystem service of natural weed control. Furthermore, rainwater helps transferring nitrogen from the sky to the soil. Rainwater contains nitrogen in forms that plants can absorb. Farmers notice that rainwater stimulates more plant growth than water from other sources, which is beneficial because they don’t need to apply as much artificial fertilizer. The additional fauna and flora which is attracted to rice wetlands, also contribute to various ecosystem services, including pest control, food resources and soil fertility enhancement.

When rice is grown out of season or outside floodplains, irrigation supply is required to generate and maintain these ecosystem services when needed. Irrigation supply is limited. Areas such as the Central Plains of Thailand have abundant access to irrigation infrastructure, but even so, water supply for rice production is not guaranteed, particularly in drought years. Rice is only one amongst several competing uses for irrigation supplies.

2.2.1 Study objectives

In this component of the TEEBAgriFood study, we analyse rainwater supply, water quality and water footprint in sustainable and conventional rice cultivation practices. The purpose of this analysis is to measure and value hydrological ecosystem services, which we would expect would be provided differently in the future under alternative scenarios. The two key ecosystem services to be assessed are: water supply and water quality amelioration.

2.2.2 Methods

This component of the study consists of firstly a *literature review* on water supply, water quality and water footprint of rice production in Thailand and other countries under different rice practices. Similarities/differences between the two rice cultivation practices will be described, including land preparation and tillage; methods of planting; farm maintenance, and harvesting.

Secondly, the team will carry out *measurements of water supply, water quality parameters* and *water footprint* according to the methods outlined below. These measurements will be inputted into the CROPWAT 8.0 model to project hydrological ecosystem service differences under different land uses in future according to the proposed scenarios.

Thirdly, the study will gather and assess quantitative and qualitative data on rice farming practices and farmer adaptation to climate change.

Figure 8 depicts a methodological framework of the water use study in different rice cultivation: sustainable rice vs conventional rice practice.

The following parameters of cultivation practice will be included in the biophysical model:

- Type of planting (e.g., sowing, transplanting, rain-fed, irrigated, alternate wetting & drying (AWD) cultivation)

- Farm maintenance e.g., fertilizer application, pesticide application, crop rotation, agroforestry practice (i.e., planted trees on paddy borders and native/wild trees on paddy fields – referred to as "trees on farm").
- Water rights and accessibility to irrigation supply
- Farmer adaptation to climate change, especially to floods and droughts, including water storage (e.g., small ponds on farmland), crop selection and switching (e.g., rice variety and amounts of planting paddy adjustment and switching from rice to other cash-crops e.g., sugarcane and cassava).

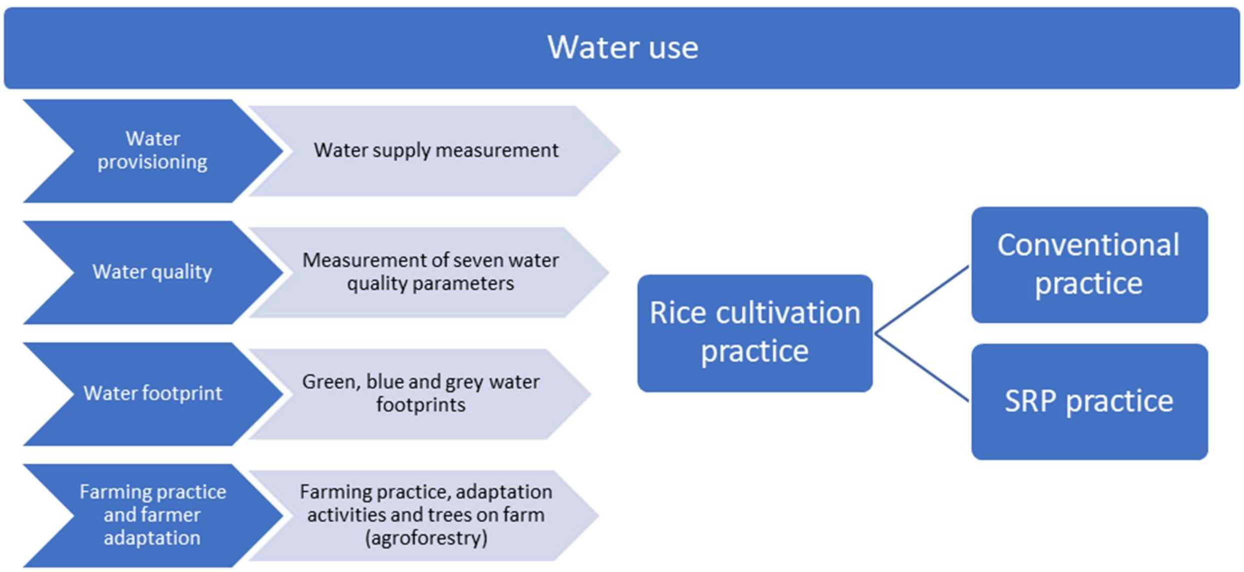

Figure 8. Methodological framework for the study on water use in rice cultivation.

2.2.2.1 Measurement of water supply

To quantify water supply, the approach proposed in this study is based on parameters which are available from meteorological and hydrological datasets. Thus, the water supply (WS in mm/year) is estimated following Equation 1 (Mastrorilli et al., 2018; Meijer et al., 2012):

$$WS = S_{PTC} - ET - EF \qquad \text{(Equation 1)}$$

where S_{PTC} is the precipitation water (mm/year), ET is evapotranspiration (mm/year) and EF is the water requirement for maintaining the aquatic ecosystems (mm/year). EF data are sourced from previous studies in Thailand's which have developed EF records.

2.2.2.2 Measurement of water quality

Seven parameters (Table 1) of physical and chemical characteristics of surface water will be measured to examine water quality from different rice cultivation practices: sustainable rice vs conventional practice.

Three of these parameters will be compared against Thailand's surface water quality Standard, developed by the Pollution Control Department. This will assess whether surface water satisfies the criteria for Class III quality: Fair condition, with some pollutant contamination, suitable for consumption after customary water treatment and disinfection processes and for agriculture. The Standard requires a pH value of between 5-9, a minimum level of dissolved oxygen level of 4 mg/L, and a maximum level of nitrates (NO_3) of 5 mg/L.

In this study, there are no parameters of water pollution to be measured that relate to human and animal health.

According to previous analyses of nutrient contamination from rice cultivation process, nitrogen recovery (in which nitrogen is finally released back to the atmosphere as N_2 gas) rarely exceeds 30-40% in wetland rice cultivation systems. Rice is primarily grown in clay soils, thus restricting N loss by leaching. Phosphate fertilizer is generally applied as base fertilizer before transplantation of paddy rice. Concentration of phosphate in surface drainage has been reported to gradually decrease throughout the entire growth period, but the phenomenon may be different in case of all year loading with low levels of precipitation (Wu et al., 2022).

Table 8. Seven water quality parameters to be measured from different rice fields.

Physical parameters	Chemical parameters

Turbidity	Acidity / alkalinity (pH)
Total dissolved solids	Salinity (% salinity and electrical conductivity)
	Dissolved oxygen (DO)
	Nitrate concentration (NO_3)
	Phosphate concentration (PO_4)
Thailand's Water Quality Standard for surface water: Class III Fair condition – with some pollutant contamination, suitable for (1) consumption after customary water treatment and disinfection processes and (2) agriculture (Pollution Control Department, 1994)	

2.2.2.3 Estimation of water footprint

The volumetric footprint of water represents the amount of freshwater used in rice cultivation, from land preparation to crop harvesting. This includes irrigation water (blue water), rainwater (green water) and water required to dilute polluted water to reference quality (grey water). On average, rice cultivation in Thailand has a water footprint of 1,665 m^3/t. This is the equivalent of one hectare of rice cultivation requiring about 6,340 m^3 of water per ha.

Different rice varieties have different water demands and cope differently to water shortage. Khao Dawk Mali 105 has the highest water scarcity footprint (598 m^3 H_2O e/t paddy rice) as the Northeastern area where it is cultivated, has the highest water stress index (Mungkung et al., 2019).

AWD water management technique is assumed to help reduce amounts of water use in rice cultivation with minimal impact on rice yield. Lampayan et al. (2015) reported that demonstration trials and training in eight countries in Asia with large scale adoption in the Philippines, Vietnam and Bangladesh illustrated that AWD has reduced irrigation water input by up to 38% with no yield reductions if implemented correctly.

For rice crops, total water demand will be estimated by adding amounts of water required in each of the crop cultivation stages, including land preparation (soil saturation), planting (standing water layer, percolation and crop evaporative demand) and harvesting (land drying). The water footprint of paddy rice (m^3/unit) is calculated as the ratio of the total volume of water used (m^3/year) to the quantity of the production (ton/year).

The total water footprint of the process of growing rice (WF_{total}) is the sum of the green, blue and grey components (Equation 2) (Hoekstra et al., 2011):

$$WF_{total} = WF_{green} + WF_{blue} + WF_{grey}\ [m^3/ton] \qquad \text{(Equation 2)}$$

The green component in the water footprint of the process of growing rice (WF_{green}, m^3/ton) is calculated as the green component in crop water use (CWU_{green}, m^3/ha) divided by the crop yield (Y, ton/ha) (Equation 3). The blue component (WF_{blue}, m^3/ton) is calculated in a similar way (Equation 4):

$$WF_{green} = CWU_{green} / Y \qquad \text{(Equation 3)}$$

$$WF_{blue} = CWU_{blue} / Y \qquad \text{(Equation 4)}$$

The grey component in the water footprint of growing rice (WF_{grey}, m^3/ton) is calculated as the chemical application rate to the field per hectare (AR, kg/ha) times the leaching-run-off fraction (α) divided by the maximum acceptable concentration (c_{max}, kg/m^3) minus the natural concentration for the pollutant considered (c_{nat}, kg/m^3) and then divided by the crop yield (Y, ton/ha) (Equation 5).

$$WF_{grey} = [(\alpha \text{ x } AR)/(c_{max} - c_{nat})]/Y \qquad \text{(Equation 5)}$$

The green and blue components in crop water use (CWU, m^3/ha) are calculated by accumulation of daily evapotranspiration (ET, mm/day) over the complete growing period (Equation 6 and 7).

$$CWU_{green} = 10 \text{ x} \sum_{d=1}^{lgp} ET\ green \text{ (volume/area)} \qquad \text{(Equation 6)}$$

$$CWU_{blue} = 10 \text{ x} \sum_{d=1}^{lgp} ET\ blue \text{ (volume/area)} \qquad \text{(Equation 7)}$$

where ET_{green} represents green water evapotranspiration and ET_{blue} water evapotranspiration. The factor 10 is applied to convert water depths in millimeters into water volumes per land surface in m^3/ha. The summation is done over the period from the day of planting (day 1) to the day of harvest (lgp stands for length of growing period in days).

2.2.2.4 Investigation of farming practice and farmer adaptation to climate change

This study will also examine farming practices that may affect water use, including the maintenance of trees on farm (agroforestry), water rights and accessibility to irrigation, and farmer adaptation to climate change. Data will be obtained from the questionnaire survey, a trees on farm inventory and will be supplemented by secondary data. This will identify farming practices, access to water, farmer adaptation activities to climate change i.e., flood and drought, and the number of tree/plant species on paddy fields on sustainable and conventional rice paddies in the Northeast and Central Plains. The number of tree species and the total number of trees will be recorded to create a species list, and assess total tree density. These data will be tested against different rice cultivation practices: sustainable vs conventional rice in the two regions.

2.3 Biodiversity in sustainable rice agriculture landscape

In Thailand, the ecological characteristics of the landscape are dominated by mosaic agricultural land use composition. The most extensive agriculture land use is rice field. It is well known that rice agriculture practice is supports high biodiversity. This is because most rice fields are governed by diverse regimes across the cultivation processes (Edirisinghe and Bambaradeniya 2006; Bambaradeniya et al. 2004). The practice for managing monoculture rice crops, from seedling to harvesting, can quickly change rice fields into various states based on water supply and drainage regime, as well as temperature, soil type, topography, and location. Therefore, in the short term, within a single crop rotation, the ecosystem of the rice field encompasses a diversity of habitat states that are ephemeral and provide a variety of niche species to diverse rice forms (Bambaradeniya et al. 2004).

The biodiversity of organisms at the landscape level is strongly related to landscape structure, landscape composition, and landscape arrangement. These landscape variables are fundamental for a landscape's ecological process and service. To understand the biodiversity of organisms in rice fields, the spatial and temporal scales of the surrounding landscape need to be included altogether with vertical compositions in food chain. The adjacent mosaic ecosystem provides an additional source of biodiversity for rice fields by offering heterogeneity to the network of ecosystems (Dermiyati and Niswati 2014). The interactions between organism and environmental factors, including agronomic practices, affect the structure of rice field ecosystems, which consist of a population of the diverse trophic cascade (Simpson et al. 1994).

Therefore, a comprehensive evaluation of the association between biodiversity and landscape characteristics is needed in conserving biodiversity in the rice field ecosystem.

2.3.1 Conceptual framework and methods for analysis of biodiversity at landscape level

This component of the study will include three frameworks; 1) landscape characteristic analysis framework 2) fieldwork for biodiversity sampling framework and 3) biodiversity in the landscape modeling framework. The landscape analysis framework will focus on analyzing landscape characteristics and configuration of the agricultural landscape and ecological context in the northeast and central regions of Thailand, which associate with the presence of biodiversity pool and local features. The characteristic and configuration of the landscape will then be used for the design of the fieldwork sampling scheme. The fieldwork will focus on organism sampling in rice field and other adjacent habitats as the baseline data for local biodiversity pool. Lastly, data from the first and second frameworks will be integrated and used as an input to model biodiversity in the landscape for scenario analysis.

The study will specifically identify the following:

- landscape mosaic structures of the northeast and central regions of Thailand.
- biodiversity of insects in the rice field, situated in different levels of landscape mosaic.

The study will predict insect biodiversity of rice fields at the landscape level across the study area and model the relationship between landscape configuration and insect biodiversity. NB In this study, the term "insect" will be taken to mean both insect species and spiders, given that both terms are translated into Thai as "*malaeng*". The more correct term "arthropod" will not be used in this study.

- Land use-Landcover and proximity to each landcover type
- Landscape metrics
- Rice farming practices

As this study is focused on impacts at landscape level, only insect biodiversity will be included in the biodiversity modelling. Information on other species will be collected from the household survey, from live traps at each sampling site. This information will be presented in a quantitative and qualitative analysis. However, data obtained on species other than insects is not expected to be sufficient to allow us to analyze related biodiversity at landscape level.

2.3.2 Landscape sampling schemes

1. Stratified clustered sampling based on
    - Distance to a forest (or wildland)
    - Elevation
    - Climate zones
    - Farming practices based on scenarios
    - Hydrological features

2. Clustered sampling – 25 clusters (5-6 sampling sites per cluster)

2.3.2.1 Biodiversity sampling at each sampling site

1. At each sampling site, aerial insects will be examined with a sweep net or vacuum sampler to collect arthropods that live in rice fields. Species of the insects will be identified, and the number of individuals of each species will also be recorded.
2. Other biodiversity will be collected using a live trap with bait to assess other vertebrates and invertebrates in the rice paddy field. Fishes and other organisms that came into the traps will be identified and counted for numbers.

2.3.2.2 Landscape modeling approach

The biodiversity indices at the landscape level will be predicted using machine learning methods. The landscape covariates composed of land use/land cover, water, soil, terrain, climate, and landscape metrics are variables that will be input into the modeling framework depicted in figure 9.

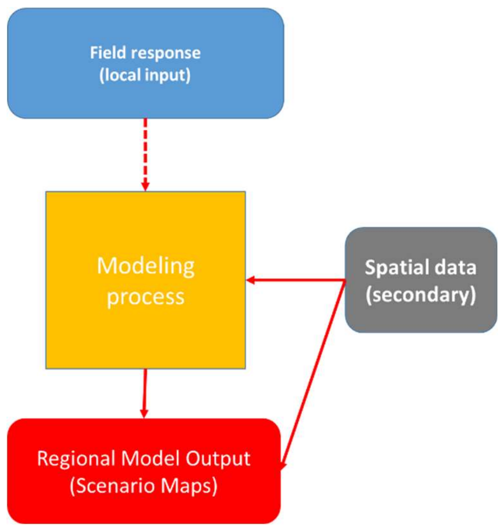

Figure 9. Modelling framework of landscape biodiversity response.

2.4 Health impacts analysis

This component of the study seeks to measure health impacts of different rice practices on farmers and general public. The health risks arising from rice production in this study include the potential health risks to farmers associated with the use and misuse of each of the agricultural pesticides applied to rice production, as well as the health risks to the broader population associated with air pollution from post-harvest rice straw burning.

2.4.1 Health-related economic costs of exposure to pesticides used in rice systems

While pesticides are used in rice cultivation for the purpose of increasing productivity, it also leads to higher health risks for people as pesticide concentrations in the environment increase.

In this study, we focus on farmers' practice. The health effects of pesticides are investigated on farmers and farm workers. Many farmers, both men and women, are directly exposed to pesticides. This includes farm workers who spray pesticides, those who mix and load the pesticides, sow pesticide-infused seeds, work on weeding and harvesting sprayed crops, and those who clean and dispose of the containers (Tago et al., 2014), as well as those who wash the clothes of the workers. Local communities, adjacent to rice fields, including homes, schools, restaurants, businesses, are also exposed to pesticide contamination, however impacts on these communities are out with the scope of the pesticide risks analysis in this study.

The health effects of pesticides depend on the amount and specific chemicals in the pesticides. In general, the main chronic health effects are cancer, neurological effects, diabetes, respiratory diseases, reproductive health, fetal diseases, and genetic disorders. Therefore, farming with non-chemical pesticides would certainly reduce the health risk for farmers.

We plan to identify the effects of pesticide on farmers' health and to measure them in form of monetary value. We will use data from two sources. The first one is from the household survey. In the household survey, there will be questions regarding the pesticides used in rice field by farmers. These questions will cover the issues as follows

- Types of herbicides, insecticide and other agrotoxins applied in the rice field
- How much is applied in each cropping season
- A set of questions asking how farmers, men and women, prepare themselves before and after using pesticide and insecticide, including clothes washing
- A set of questions to identify respondents' symptoms and sickness from pesticide poisoning.

Besides using survey to identify impacts of herbicide, insecticide, and other agrotoxins on health, we plan to use information from literature, for example Atreya et al. (2012) that identify probability of falling sick or death from misuse by different types of pesticide regularly applied in rice field from our study areas. This will allow us to analyse broader risks of pesticide misuse on long term health outcomes that the household survey of symptoms may not be able to clearly identify. The probability identified from literature will then be used to calculate the potential number of farmers who fell sick or died due to exposure to each type of pesticide based on land use changes of scenario. To monetize the impact of pesticide on health of farmer, cost of illness (COI) and defensive expenditure (DE) concepts will be applied.

The COI is defined as lost productivity due to illness plus the cost of medical treatment due to illness (Freeman 1993; Freeman et al., 2014). This method is often used to assess the health risk of pesticides because of its ease of use (EPA 2000). The COI is composed of (1) the opportunity cost of days lost to pesticide-related illness and (2) the cost of medical treatment.

The defensive expenditure approach (DE) is used to evaluate the willingness to pay (WTP) for behavior to mitigate potential risks of pesticide exposure. Defensive expenditures include the cost of safety measures adopted prior to spraying to reduce the risk of pesticide exposure.

2.4.2 Health-related economic costs of exposure to PM 2.5 from rice burning

This section of the study focuses on the negative impacts of burning related rice residues on human health. According to the SRP Standard[21], one of the core requirements to be able to claim "Sustainably Cultivated Rice" is that rice stubble (or rice straw) is managed in a sustainable manner to reduce greenhouse gas emissions, reduce environmental impacts, and maintain or improve soil quality. Thus, SRP certified farmers must avoid burning rice stubble under harvest and post-harvest. The standards of GAP rice production and Thai agricultural products' food safety standards[22] do not restrict the post-harvesting practice of rice open field burning.

One recommendation of the GAP food crop standards is that the soil quality for the next cultivation should be maintained in the area. This could mean that burning in open fields should be avoided because it can damage the soil properties. Up to date, the sustainable rice practice in Thailand has officially stated that open field burning of rice residue (i.e., rice straw and rice stubble) is prohibited for sustainable rice practice cultivation.

This study assumes therefore that the source of residue burning on rice fields is not the sustainable rice practice area. Thus, the area of conventional rice production is the possible source of residue burning, which will be used to estimate the health cost of rice production.

[21] Sustainable Rice Platform Standard for Sustainable Rice Cultivation (version 2.1, 2020) https://www.sustainablerice.org/wp-content/uploads/2021/10/103-SRP-Standard-Version-2.1.pdf

[22] Rice department, MoAC. http://e-gap.ricethailand.go.th/page2.html and the National Bureau of Agricultural Commodity and Food Standards(ACFS) (http://e-book.acfs.go.th/backend/uploads/Download/103a14f76c65cc5236b44dd0c174fe9f.pdf)

To begin with, open field burning is used to assess rice residue burning. The emission in this paper is based on a field experiment done in Thailand (Junpen et al., 2018). The assessment of rice residue burning is subject to open field burning. In this study, the emission is based on the field experiment conducted in Thailand (Junpen et al., 2018). Using Equation 1, we calculated the emissions from biomass open-burning as follows:

$$E_i = M \times EF_i \times 10^{-3} \quad (1)$$

where E_i is the air pollution emission; M denotes the mass of dry matter burned (t of dry matter) ; and EF_i is the emission factor of the air pollutant *i* (g/kg of burned dry matter). The value of emission factor in this study is used as $EF_{PM2.5} = 8.3$

Next, the study focuses on the emission of PM2.5 concentrations caused by rice straw burning. According to Junpen et al. (2018), calculating the dry mass burned of rice straw in a field (M) is dependent on the amount of rice residue subjected to open field burning. Estimation requires three components: the rice harvested area, the amount of rice residue per unit area, and the fraction of rice residue subject to open field burning. The burning scenarios are based on the transition of rice production from conventional rice production to sustainable rice practice production. Based on the early assumption, the rice harvest area in Equation (1) only yields values for the conventional rice production area. It should be noted that the data for the sustainable rice area defined by this study comes from a parallel study in which a pattern of land use change is predicted from 2030 to 2050. In the following step, the result of PM2.5 emission is used to assess the human health impacts.

The health impact of PM2.5 is calculated using an exposure-response function or a concentration-response function and the pollutant concentration. Depending on the health endpoint, health impacts can be classified into two types. It is divided into two categories: mortality and morbidity. Both concepts relate to the change in morality or mobility rates of health endpoints as a percentage change per 10g/m3. Either the occurrence of disease or the occurrence of mortality follows a conventional Poisson distribution presented by equation (2). To minimize duplication counting of health endpoints, The International Classification of Diseases report (ICD-10) considers the health consequences of various diseases and mortality. In this study, the health effects of PM2.5 will be calculated in terms of premature mortality due to respiratory system disease. In this respect, the valuation of premature mortality refers to a potential number of years of life lost before the age of 70 due to exposures to PM2.5 air pollution and is calculated in monetary terms. The population of each province will be projected ahead based on a 0.28 percent annual growth rate to quantify the health implications across the burning scenarios. Equations (2) and (3), which show the following, estimate the population exposure to PM2.5 and health damages caused by PM2.5 exposures.

$$ER_i = ER_{0i} \times e^{\beta_i (C - C_0)} \quad (2)$$

$$H_{ij} = P_j \times (ER_i - ER_{0i}) = P_j \times ER_{0i} \times [e^{\beta_i (C - C_0)} - 1] \quad (3)$$

where H_{ij} denotes the health impacts i in the province j under the level of PM2.5 concentration *C*. P_j is the exposed population in the province j. ER_i refers to the incidence of health end point under the level of PM2.5 concentration *C*. ER_{0i} is the baseline incidence of health endpoint *i* of the affected population. It represents the changes in incidence of a health impact per i µg/m3 increments of PM2.5. β_i refers to the exposure-response coefficient of health endpoint. The exposure-response coefficient derived from the previous literatures (Yang et al,2018; Yin et al., 2017). *C* refers to the concentration of PM2.5 from rice straw subject to open field burning, recalled from Eq.1. C_0 is the baseline PM2.5 concentration using the maximum value of recommended by WHO to avoid health problems.

The economic cost is estimated at this stage. The economic loss is calculated by developing a proxy monetary value for the risks associated with exposure to PM2.5.

Exposure to PM2.5 particles is used to determine the value of economic cost for each case scenario (Wang et al., 2020). The costs are estimated using the Amended Human Capital (AHC) technique in this study. AHC is calculated with reference to the loss of productivity of the entire society as a result of individual absence from work, and then corrected with the gross domestic product per capita, depending on the health implications under consideration.

AHC is frequently used in conjunction with a statistical life value to value health impacts (VSL). The lower and upper bounds of calculating health expenditures are calculated using the AHC and VSL methods. The willingness to pay for a marginal reduction in fatal risk (Hammit,

2000) is used to calculate VSL, which is then converted to disposal income. VSL is frequently used to assess the cost of medical treatment, hospitalization, and lost productivity, as well as to calculate the cost of disease.

This study will not cover morbidity in terms of long-term diseases like chronic bronchitis, as there is a lack of information on medical expenses and productivity loss.

In epidemiology and economic literature, the AHC is frequently used to assess the loss of human capital value caused by air pollution, particularly fine particulate matter (Huang et al., 2012; Yin et al., 2015; Yin et al., 2017). The possible sickness induced by PM2.5 is drawn from Thai research initiatives (Jenwitheesuk, K., Peansukwech, U., & Jenwitheesuk, K. (2020)) as well as earlier evidence (Yin et al., 2015) based on ICD-10 reports. As a result, employing the AHC technique, this study focuses on the health effects of PM2.5, particularly premature mortality induced by PM2.5. According to the AHC, individuals are seen as the fundamental unit of human capital, providing goods and services. This method assesses the loss of life and health using a general criterion for assessing physical capital, which is typically represented as wage or labor capital. The HC method simply considers the predicted income loss as the loss from early mortality.

$$AHC = GPP_{j0} \cdot \sum_{k=1}^{t} \frac{(1+\alpha)^k}{(1+\gamma)^k} \tag{4}$$

The amended human capital per case is expressed in Eq. (4). It was calculated based on a gross provincial product (GPP) of province j in year k (GPP_{j0})[23], α is the per capita GPP growth rate, and γ is a social discount rate[24], t is the average number of life-years lost due to exposure to PM2.5 at a given concentration, which is assumed to be 10 years (Yang et al., 2015).

Based on rice production scenarios, the health cost related to exposure to PM2.5 from different rice practices production will be assessed. We expect that as the area of conventional rice production decreases with the expansion of sustainable rice cultivation area, the health cost tends to extensively decline.

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[23] A based year is 2012. The statistic of GPP applied from the Office of the National Economic and Social Development Council in 2018

[24] Social discount rate refers to a present value on cost and benefits for economic evaluation that will occur in the future. The social discount rate usually use between 3%-7% in developed countries and between 8%-15% in developing countries (Medalla, 2014). In the context of health impact, the parameters values of the social discount rate are 8%.

2.5 Production impacts

2.5.1 Methods for assessing produced capital impacts

The produced capital analysis will be based on household survey data relating to investment cost, generated income, saving, and debt to quantify the economic status. Moreover, the post-harvesting information on rice cultivation, the generation of solid waste from cultivation practices and other crops after rice cultivation will be quantified.

2.6 Socio-economic perspectives

2.6.1 Methods for assessing the socio-economic context of rice farming

The different rice practices impact directly on farmers' economic situation, social status, and decision behavior. The socio-economic data of conventional, organic and sustainable rice practice farmers will be examined by a household survey. In addition to the specific uses of data referred to in the methodologies for biophysical modelling outlined above, the household survey data will also be analyzed for additional quantitative and qualitative analyses.

The questionnaire would identify subjective well-being/happiness concerning occupation, family life, financial status, health, and other things that matter, as well as social relations in the community. The questionnaire also explores the driving factors why farmers adopt, do not adopt, and why they continue or stop applying sustainable rice platform practices. The scope of key issues in the questionnaire are presented in table 9.

Table 9. Household Questionnaire – Key to issues investigated.

Question issues	Relationship to the indicators of stocks, flows, and outcomes
Happiness (Subjective well-being)	Subjective well-being/ happiness in social capital in general and specific time period.

Question issues	Relationship to the indicators of stocks, flows, and outcomes
	The main dimensions of subjective well-being are measured toward such as occupation, family life, financial status, health, and things that matters to you, etc. Well-being relates to health issues, including the medical expenses if incurred.
Agricultural land information	A general characteristic of agricultural land is observed on: Landownership / size of agricultural land, cost of rice production and preferred rice variety, particular agricultural activities
Rice cultivation practices	All cultivation practices related to rice cultivation, both rice production and post-harvest crops during dry season to capture flow of all inputs and outputs. This includes volume and type of labor, pesticides, fertilizers, seeds, machine rental.
Post harvesting information	Practices during post-harvest to assess outputs associated to flow of residuals.
Observed biodiversity	The living small animals found in the paddy field throughout the cultivation process can be indicated as income and household consumption.
Choice of management system	Whether or not sustainable rice platform practice is undertaken. Driving factors that motivate farmers to uptake the sustainable rice platform can relate to the regression framework of adoption decision. What causes farmer to give up the practice of sustainable rice platform production?
Environmental problems	Farmer perceptions and attitudes to environmental problems in general, including pollution and natural disasters.
Income and spending	Main sources of off-farm income such as salary, wage, and remittance. Analysis of off-farm income will be included in the social capital assessment. Dividends from cooperatives identifies the returns on investment. Gender equity in cooperative membership and shareholdings can also be explored.

Question issues	Relationship to the indicators of stocks, flows, and outcomes
	Items to identify monthly spending behavior of household.
Household saving and debt information	Data to be used as proxy for financial status of household
Social capital	Trust and social networks capture the stock and outcomes of social capital in community. Trust and social relations

Since we plan to use data from conventional rice farmers, sustainable rice farmers, GAP and GAP++ farmers, as well as farmers who join the mega farm program, the approximate sample size of the study will be calculated using a stratified random sampling scheme, which will be based on not only the practices but also the geographical factors, i.e., regions, weather conditions, irrigated and non-irrigated areas. The expected sample size for the household survey would be a total of around 800 households.

Responses to the household questionnaire will be applied for quantitative and qualitative analysis of advantages of and barriers to adapting sustainable rice practice, in terms of natural capital, produced capital, human capital, and social capital.

The human capital will concern farmers' health and knowledge related to subjective well-being/happiness concerning occupation, family life, financial status, health, and other things that matter.

The social capital will describe social network, trust, as well as women' activities in the rice production. The research team plans to elicit the social network regarding to agricultural information diffusion and imitation to identify the nodes and their characteristics that may be able to use as initial information to spread information of sustainable rice practice to other members in their networks.

2.5.2 Consumer preference

Like other environmentally friendly products, the sustainable rice product needs a consumer pull instead of only a supply push. There are studies showing that consumers are willing to pay a premium price for quality rice. The Viet GAP rice has a price premium of 9 percent to 33 percent than conventional rice when levels of certification and traceability are available (My, Nguyen HD, et al., 2018). In the same study, it was assessed that organic rice could have a price premium of 82 percent, as well as the integrated pest management rice could have 45 percent of price premium compared to conventional rice in Vietnam (My, Nguyen HD, et al., 2018). In Nigeria, the consumers also concern of sustainable rice practices related to food safety and health safety issue (Okpiaifo, Glory, et al., 2020).

In Thailand, sustainable and healthy rice also attract premium prices (Beisiegel, L., 2014). Therefore, the value of consumers' preference for sustainable rice product could be one of important issues to drive sustainable rice practice adoption. Understanding consumers' preference and perception toward the benefits of sustainable rice practice are crucial. Therefore, we plan to collect survey data to understand consumers. Specially, perception of consumers regarding to the effects of sustainable rice practice on direct benefits such as consumers' health safety, and indirect benefits such as biodiversity and GHG emissions will be explored and monetized to estimate the benefit values generated from consumers' perspective.

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Appendix 1: Summary of focus stakeholders meeting on on 31st August 2021

Impact	Organizations	Topic
Environment	Government Sector	
	Farmer	- The use of chemicals affects both the taste and shelf life of cooked rice. : The more chemicals used; the worse the rice's flavor becomes. : The higher the chemicals content, the faster the cooked rice rots. - Chemicals in rice cause grain damage, making it more difficult to cultivate in the future and reducing its shelf life. - Alternating wet and dry farming can strengthen rice stem and cause more rice tillering. - Weeds, especially during the dry season in the northeastern region, attract insect pests, leading farmers to use pesticides. - Chopping the rice leaves can help solve weed problems. - When rice spends a shorter period of time in the field, the soil has more time to be nourished and thus has more nutrient-dense.
	Mill	
Health	Government Sector	
	Farmer	- Farmers' mental health and quality of life will improve if SRP rice is certified and more demand is generated. - When it comes to the use of chemicals, farmers are more concerned about rice yields than its effect on their health.

	Mill	
Economy	Government Sector	- identifying the target market - The Government needs to establish common standards by finding a major problem to be an intermediary.
	Farmer	- The uncertainty of the market makes it difficult for the farmer to change. - Farmers usually sell rice to one who is close to them or those in the same area. - The increased in rice prices are the motivating factor for the farmer to change. (Having a certificate certifying that rice is grown in accordance with SRP principles) - Farmer's lack of market and export knowledge as compared to mills and other organizations (Asymmetric information). - The mills must operate in strict accordance with the sorting standards. - The mills are unable to provide complete support to the farmer. As a result, the government should provide financial support to these mills in order for them to increase their rice purchases.
	Mill	- The planting plan for SRP rice, as well as the cultivation processes, must be explicit and verifiable. - It's important to find the strength of SRP because most of the mills already has a purchase standard of GAP and organics. - The sales market will be unequivocal only when SRP standards are clear. - The price that the mills are willing to offer depends on the market demand.
Skills	Government Sector	- Pass on knowledge to people who are truly interested and create roles model.

and Knowledge		- Role model is someone who is similar to the farmer (farmers who live in the same area).
	Farmer	
	Mill	
Social	Government Sector	- It's very difficult to change to the new standard, especially for the groups of farmers who use the conventional method of cultivation. - Adjusting farmers' perspectives by using successful local farmer as role models. - Instead of engaging as a leader, the government should provide support in other areas. - As a leader, the government causes plenty of issues by inciting farmers to focus solely on profit and overlook the importance of long-term sustainability. - Create a strong local organization and extend it in order to achieve sustainability development.
	Farmer	- After a termination, the transfer of responsibilities of government agencies results in discontinuous work or a failure to continue the development of ongoing activity.
	Mill	
The future of SRP rice	Government Sector	- find the strength of SRP rice. - find the motivation factors that can lead people to switch to SRP rice. : Increase productivity. : Increase the purchasing power of the mill. : Reduce the cost.

		: Improve the quality of rice. - Promote SRP rice consumption in schools and hospitals. - From the perspective of fair trade, it is critical for SRP rice to provide benefit for all stakeholders, from upstream to downstream.
	Farmer	- There should be a chemical detector and a rice classifier in the field. - Reduce the process of requesting a certificate because it is complicated and expensive.
	Mill	

Total person meeting: 28 persons

- Government sector: 14
- Famers: 8
- Mill: 1
- KKU team: 5

Female: 14, Male: 14

Appendix 2: Summary of the stakeholders meeting on 4th October 2021

Topics	Points raised in the discussion
Environment	• Laws and clearly punishment for destroying the environment from rice production could been purposed by the Thai Government especially for rice stalks burning in land preparing process because it makes pollution in soil, water, and weather. • Sunn hemp is the best choice for repairing the soil. • The rice stalks burning is a big problem for the environment, so the villagers suggested that selling rice stalks to orchards or plough up and over in the case of remaining rice stalks should be the beneficial method. • However, the rice stalks burning is not always a bad way because some diseases can be eliminated by this method. • using "Trichoderma" instead of chemical pesticides was recommended by the villagers in Pathum Thani because it also can protect the rice from insects, pests, and diseases. • The cost of using Trichoderma makes villagers choose the rice stalks burning method. • Annual rice cultivation makes environment abundant. • Renting lands is the one factor that force farmers to use the method of rice stalks burning because it's convenient and fast for non-season rice. The reason behind that is, there is no official contract between the farmers and landowner, so the rent price depends on owner. To worth for the cost of renting, farmers have to rapidly prepare the soil to grow the non-season rice instead of repairing the soil for the next annual rice. • The important resource for rice production is water.
Economy	• Farmers could use the transplanted rice method or other methods instead of sowing seeds to decrease the cost because the number of grains in sowing method used the seed more than other methods. (Sowing method use 20-25 kg. /Rai while transplanted rice method used 10 kg. /Rai)

	• Trichoderma is rare and high cost because Trichoderma have to use many times and cannot combine with other substances. • There is no official contract for rent lands, so the cost is not stable in the long run. • Sunn hemp can help the villagers to decrease the costs for preparing the soil. • Rice lodging problem cannot fix by Trichoderma. • The farmers concerned about the market and price. • The low price and no demand from mills cause farmers cannot management rice production. • Subsidy the small rice mills and the villagers processed rice because it can safely cost and increase in value. • Excess supply it makes lower price.
Health	• Comparison before and after of using chemical and Trichoderma in rice production of farmers fond that the health trend to be better while the contaminated in blood trend to reduce. • The effect of good environment can make the indirect benefit to farmer health. • The health is difficult to convince the farmers because they concern the poverty more than bad health.
Knowledge	• Trichoderma is a best choice for preparing seed and make lands abundantly. • The farmers were offer and support by government agent to distribute Trichoderma. • Weedy rice problem is argument that cause from the tractor which sharing between the farmers in Northeastern and Central of Thailand.
Social	• The group of the large-scale of rice production can make the productive of rice production and attract the external organization to help them because it is easy to contact and handle. • The case of Pathum Thani, some farmers were banned from burning stalks rice, but it is ineffective because they have the propriety right. • Social group is an important factor for rice management because it can help farmers handle the stock and create the power of selling.

The Future SRP	• Government support in the large-scale of rice production can reduce the problem. • Government should subsidize the studies about new rice variety. • The supporting process from government make the cost for farmers such as asking a permission, invoke the help. • The rice exporting has several barriers so the farmers cannot sell the rice with the high price to foreign. If the government can manipulate this process, the excess supply and low price will be managed. • Government should subsidize rice mills to buy the high-quality rice with the high price. • The government institutions such as schools, hotels, hospital, and prison nearby the area might be the potential for farmers to make the higher profit due to the reducing cost and market competition. • Crop insurance and rice mortgage policy from the government can be used as a tool to absorb the effect of unexpected factor of farmers such as disaster, natural disaster.

Total person meeting: 23 persons

- Farmers: 18
- KKU team: 5

Female: 8, Male: 15

Appendix 3 Requirements of SRP Standard re Biodiversity and GHG emissions

SRP Performance Indicators	Requirement No	**SRP compliance minimum**	**Principle components**	How this will be included in the study
Biodiversity	**6 Land conversion and biodiversity**	**There has been no conversion of described areas after 2009.**	**Rice farming after 2009 has not been causing conversion within a (proposed) protected area, Key Biodiversity Areas™, Ramsar Sites (wetland), primary forest, secondary forest (native), or other natural ecosystems and land types such as prairie.**	Not assessed. It is assumed that the area of rice production will not expand or contract. It is assumed that no land conversion from wild spaces to rice production has taken place in the relevant regions since 2009
			At the field level, farmer maintains and/ or enhances applicable site-specific biodiversity elements: • **In-field habitat / refuge** • **Field margins** • **Non-cropped area** • **Plant species which host beneficial natural enemies** • **Trees (replanted if harvested)**	Assessed
			Farming practices maintain and/or enhance ecosystem services.	Assessed
Biodiversity	7 Invasive Species	No invasive species are introduced intentionally by the farmer or group since 2009.	**No invasive species (e.g., water hyacinth, golden apple snail) have been introduced intentionally by the farmer or group since 2009**	Not assessed. It is assumed that no invasive species have been introduced intentionally in the study areas.
Biodiversity	8 Levelling	Land has been leveled (no machinery required, visual confirmation sufficient).	**Rice cultivated on flat land or on terraces:** **If laser leveling is used, the land or terraces are leveled up to 1/1000 within-plot slope.** **If laser leveling is not used, visual observation confirms that the field does not have high and low spots when filled with water and crop stand is uniform in height (i.e., no undulating).**	Not assessed. The equipment needed for this technique is not yet widely available in Thailand

SRP Performance Indicators	Requirement No	**SRP compliance minimum**	**Principle components**	How this will be included in the study
GHG	**10 Water Manage-ment**	Timely and appropriate crop establishment according to local climate. Direct seeding or effective puddling, and strong bunds	**Rainfed systems - Measures are in place to enhance water-use efficiency including:** **1. Timely and appropriate crop establishment according to local climate.** **2. Direct seeding or effective puddling, and strong bunds** **3. Use of varieties suitable for local climate (e.g., short or medium-duration varieties).** **4. Provision of on-site rainwater harvesting and storage for supplementary irrigation.**	Not assessed. It is assumed that all Thai rice farmers in rainfed systems comply with conditions 1-3. It is not known the extent to which condition 4 applies in Thailand.
		Timely crop establishment to avoid submergence of the crop during expected floods.	**Irrigated Production System— Flood-Prone** **Measures are in place to enhance water-use efficiency including:** **1. Timely crop establishment to avoid submergence of the crop during expected floods.** **2. At least one dry-down event (i.e., mid-season drainage of 7 days drained period/ aeration), if possible.** **3. Leveling with provision for minor drainage conditions.** **4. Use of flood-tolerant varieties**	Not Assessed
		Leveling and strong bunds. **Alternate wetting and drying.**	**Irrigated Production System—Not Flood-Prone** **Measures are in place to enhance water-use efficiency including:** **1. One dry tillage before flooding if soil is cracked.** **2. Leveling and strong bunds.** **3. Dry seeding, or transplanting following land soak, effective puddling, and tillage within a 1-week period.** **4. Alternate wetting and drying.** **5. Use of short or medium-duration varieties with similar yield potential as long duration varieties** **6. Termination of irrigation at least 10-15 days before harvesting.**	Application of AWD is assessed
Biodiversity	**14 Drainage**	**Surface (sideways) drainage is delayed**	**Intentional surface (sideways) drainage after surface application of agrochemicals is sufficiently delayed to avoid**	Assessed

SRP Performance Indicators	Requirement No	**SRP compliance minimum**	**Principle components**	How this will be included in the study
		after surface application of agrochemicals by at least 4 days for fertilizers and 14 days for pesticides, or according to the product label.	**contamination from agrochemical runoff, or according to the product label. Agrochemical runoff can negatively impact biodiversity or surroundings and waterways**	
Biodiversity / GHG	**15 Nutrient manage-ment**	**2 of the efficient and site-specific nutrient management measures are followed**	**Nutrient Management (Inorganic And/Or Organic)** **Efficient and site-specific nutrient management is applied and documented.** **Measures for efficient nutrient management include:** **1. Timing of fertilizer (inorganic and/or organic; N, P, and/or K) application is according to plant needs, locally adapted recommendations, and product label instructions (if available).** **2. Amount of fertilizer (inorganic and/or organic; N, P, and/or K) applied is based on knowledge of soil fertility and expected yield, locally adapted recommendations, and product label instructions (if available).** **3. Natural systems of soil fertility enhancement (e.g., crop rotation, intercropping, and/or non-invasive cover cropping) are used.**	Assessed
GHG	**16 Organic fertilizer choice**	**Farmer does not use organic material as fertilizer because one or more of the listed conditions cannot be met.**	**Organic material (e.g., animal manure, green manure, mulch, rice straw) is used as fertilizer if the conditions are favorable.** **Favorable conditions include:** **1. It can be applied in non-flooded fields in composted or de-composted state.** **2. There is sufficient time for its decomposition prior to flooding.** **3. It is available locally (approximately within 50 km radius) and in sufficient quantity.**	Assessed

SRP Performance Indicators	Requirement No	**SRP compliance minimum**	**Principle components**	How this will be included in the study
GHG	17 Inorganic fertilizer choice	Farmer uses inorganic fertilizers that are registered and come from a non-counterfeit source.	**Inorganic fertilizers can be used only if they are registered and come from a non-counterfeit source.**	Not assessed. It is assumed that all inorganic fertilizer used is non-counterfeit
Biodiversity	**18 Integrated pest management**	**Preventative control methods are used, before considering curative methods. Pesticide used only if other methods not effective on their own, + if pest expected to cause significant damage or loss. Pesticide is selected as per national government recommendations, is registered for use in rice, is not on international lists*, and is not counterfeit Pesticide use is targeted to avoid non-application zones. Pesticide is applied according to product label, follows specified preharvest interval, and does not exceed dosage (for worker safety and food safety). For insects: + Broad spectrum insecticide is not used within the first 40 days after rice planted (unless in**	**IPM combines preventative and curative pest control methods.** • **Preventative pest control methods help to manage conditions to avoid pest build-up and can include: resistant varieties, crop rotation, intercropping, sanitation, ecological engineering, and others.** • **Curative pest control methods help to treat pest build-up that has occurred and can include: mechanical control (e.g., hand weeding), biological control (e.g., biological control agents), and chemical control (e.g., synthetic pesticides).** **The SRP Standard seeks to encourage ongoing preventative pest control actions, and punctual curative pest control actions when preventative methods are not effective on their own. Pesticides are used only if and when action thresholds are exceeded and the severity of the pest is expected to cause significant damage or loss. Actions should be as targeted as possible to avoid unintended impacts. Measured actions can support cost-reduction for farmers.**	Assessed

SRP Performance Indicators	Requirement No	**SRP compliance minimum**	**Principle components**	How this will be included in the study
		accordance with local government extension expert advice)		
GHG	**24 Rice stubble**	**Farmer doesn't burn rice.**	**Rice stubble is managed in a sustainable way to mitigate greenhouse gas emissions, minimize environmental impacts, and retain or improve soil quality.** **Rice straw is:** **1. Not burned.** **2. Allowed sufficient time (at least 3 weeks) for aerobic decomposition before wetting.**	Assessed
GHG	**25 rice straw**	**Farmer doesn't burn rice.**	**Rice straw is managed in a sustainable way to mitigate greenhouse gas emissions, minimize environmental impacts, and retain or improve soil quality.** **Rice straw is:** **1. Not burned.** **2. Allowed sufficient time (at least 2 weeks) for aerobic decomposition if rice straw is left on the field or plowed under.** **3. Collected, used as livestock feed and animal manure is returned to the field. Or collected, composted, and returned to the field.**	Assessed

Note: **bold font** refers to those included in the assessment