Measuring what matters in sustainable rice production

TEEBAgriFood Thailand EU-funded project

Synthesis Report

April 2024

Prepared by Khon Kaen University

The Economics of Ecosystems & Biodiversity

Funded by the European Union

Economy and Environment Institute
LOWER MEKONG SUBREGION

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TEEB The Economics of Ecosystems & Biodiversity

Funded by the European Union

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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 framework highlights 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 Economics, 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).

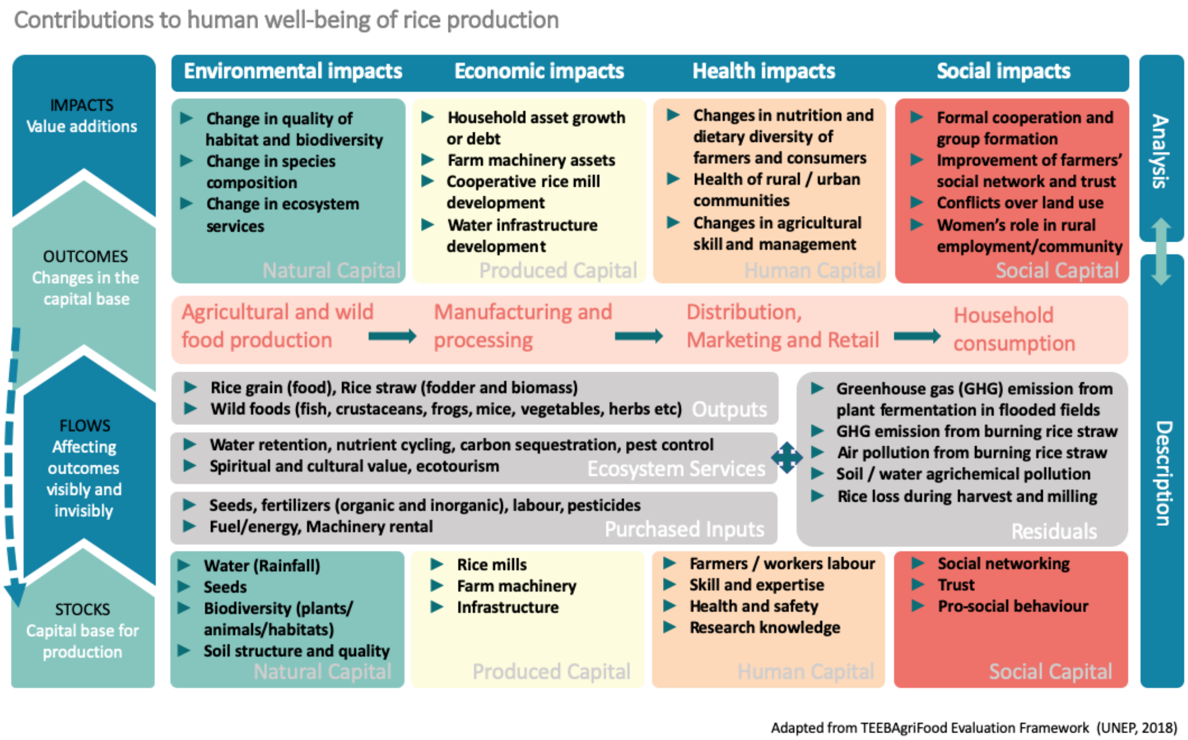


Figure 1.1: TEEBAgriFood evaluation framework applied to the rice sector

As illustrated by the TEEBAgriFood evaluation framework in figure 1.1 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 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. Introducing the TEEBAgriFood Thailand assessment on Sustainable Rice

2.1 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 outes 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.

2.2 Focus in Thailand

The research scope is 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 focuses 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.

2.2.1 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 2.1). The Standard presents a framework to support claims to sustainability.

In Thailand, the Rice Department of the Ministry of Agriculture and Cooperatives have issued 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 and English from the Bureau of Agricultural Commodities and Food Standards ACFS. 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 focuses on five key management practices that promote sustainability, which relate directly to the SRP themes of "biodiversity" and "greenhouse gas emissions".

Figure 2.1: Illustration of the 41 requirements of the SRP Standard structured under eight themes

2.2.2 Policies and plans for sustainable rice production, healthy agricultural practices

To promote sustainable rice production, standards for environmentally-friendly rice cultivation have been progressively adopted in Thailand, as described above. 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.

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 is defined by three mains strategic targets based on the 20-year

Agricultural and Cooperatives Strategy (2017-2036)[2], the 13th National Development Plan (2023-2027)[3], and the Thai Parliamentary targets relating to pesticide use regulation[4]. The details of scenario set up based on these policies and plans are explained in the "Scenario Analysis" section.

2.3 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 are analyzed in terms of changes in stocks and flows of produced, natural, social and human capital. Policy recommendations 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 is important not only to engage the Office of Natural Resources

[2] www.oae.go.th/assets/portals/1/files/bapp/strategic2560-2579.pdf

[3] www.nesdc.go.th/main.php?filename=plan13

[4] https://bit.ly/2QOj46D

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 also develops 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.

3. Scenario Analysis

The objective of conducting a scenario analysis is to assess and compare the long-term economic benefit associated with promoting biodiversity in rice landscapes against the potential implications for both farmers and the general public. The benefits and costs of different rice production systems are examined by the study team through a comparative analysis of distinct potential future policy scenarios. The primary emphasis of the scenarios is on the varying proportions of rice cultivation land allocated to conventional and sustainable rice farming approaches.

The scenarios were established by considering significant government policies and aims pertaining to the sustainable growth of the rice sector, with the objective of attaining a bio-circular and green economy, commonly referred to as the BCG economy. The scenarios focus on the different proportions of rice area under conventional and sustainable rice practices. The projected conversion of land to sustainable rice practices is modeled exclusively in areas that are currently growing rice using conventional methods. The schema is established by considering the perspectives of many local stakeholders at the study locations, such as agricultural officers, farmers, millers, merchants, and heads of farmer organizations.

National plans and policies are incorporated, namely Thailand's 20-year Strategic Plan (2017-2036), and the associated Master Plan for Agriculture. These initiatives aim to facilitate the growth of Thailand's sustainable products in both domestic and international markets. In conjunction with the agricultural policies and projects, the established scenarios are grounded in the National Master Plan on Climate Change (2015-2050) proposed by the Office of Natural Resources and Environmental Policy and Planning (ONEP), the 13th National Development Plan (2023-2027), and the Thai rice Nationally Appropriate Mitigation Action (Rice NAMA). These initiatives specifically target the mitigation of carbon emissions originating from agricultural activities.

The temporal scope of the scenarios span a duration of 28 years, starting in 2022 and ending in 2050. The TEEBAgriFood Steering Committee is chaired by the Office of Natural Resources and Environmental Policy and Planning (ONEP) and consists of agencies from the Ministry of Natural Resources and Environment and the Ministry of Agriculture and Cooperatives, along with the Ministry of Finance, Ministry of Public Health, and the Ministry of Commerce the National Economic and Social Development Council. This research focuses on rice production in

Thailand's northeast and central regions. A baseline of conventional and sustainable rice cultivation in 2020 is presented in Figure 3.1. It shows a relatively small share of sustainable rice production (red dots) in both regions. It is located mostly in the north of the central region, and disperses south and east of northeast Thailand.

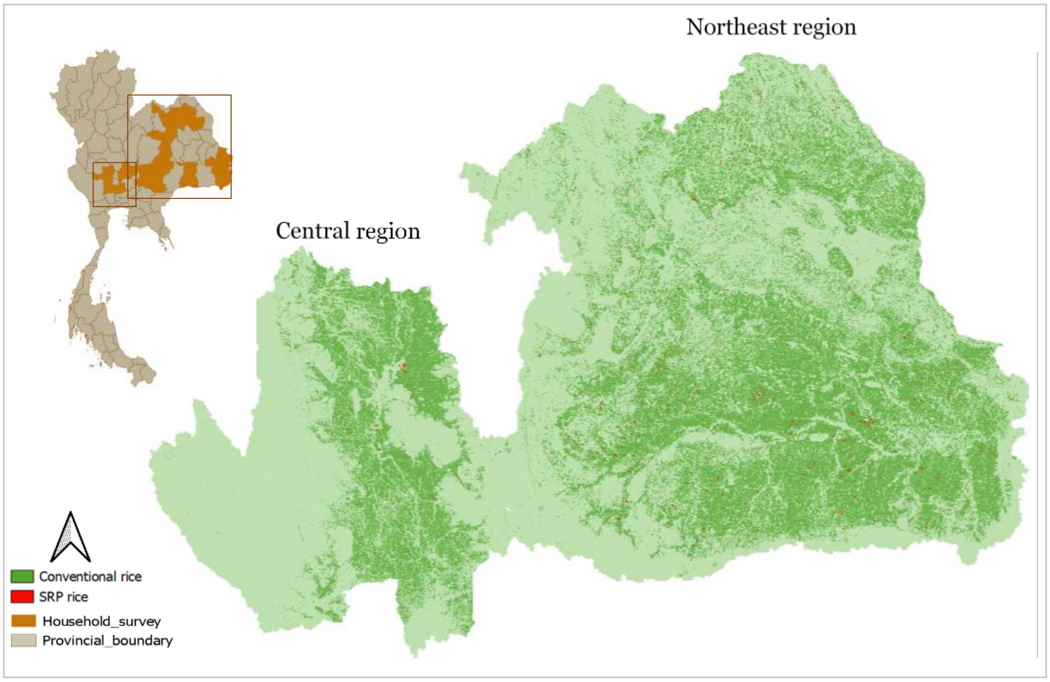


Figure 3.1 Baseline maps of conventional and sustainable rice production regions in Northeastern and Central Thailand in 2020.

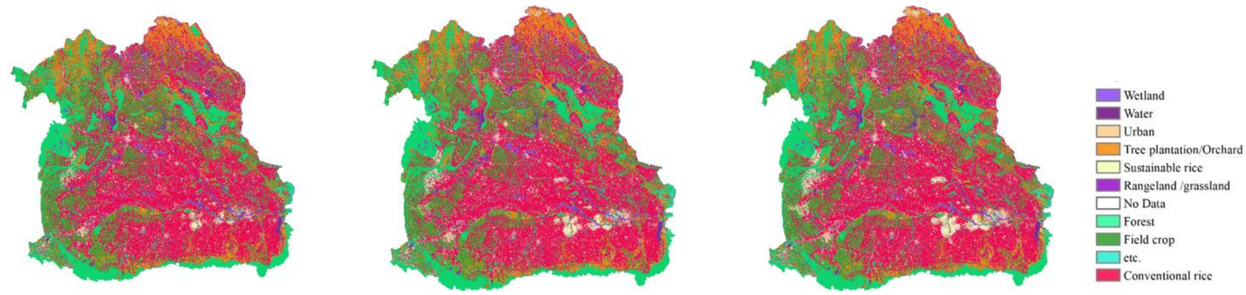
Source: Data were retrieved from the Office of Agricultural Economics and the Land Development Department, MOAC, Thailand.

Scenario 1: Business as Usual (BAU)

BAU assumes sustainable rice practice (SRP) expansion continues at the current rate. The average annual increase in GAP and GAP++ area, applied as SRP area, since 2014 is **100,000 rai (16,000 hectares**). As of 2022, 1.2 million rai (192,000 hectares) of SRP has been adopted. If this rate of increase continues, an additional 500,000 rai of rice farmland in Central and Northeastern regions, or 80,000 ha, will be converted to sustainable rice practice every five years until 2050. The Business-As-Usual scenario predicts that SRP will cover 4 million rai (640,000 hectares) by

2050, which is about 7.58 percent of the country's rice production area. Figures 3.2 and 3.3 present the changes of rice areas in Northeast and Central regions, respectively.

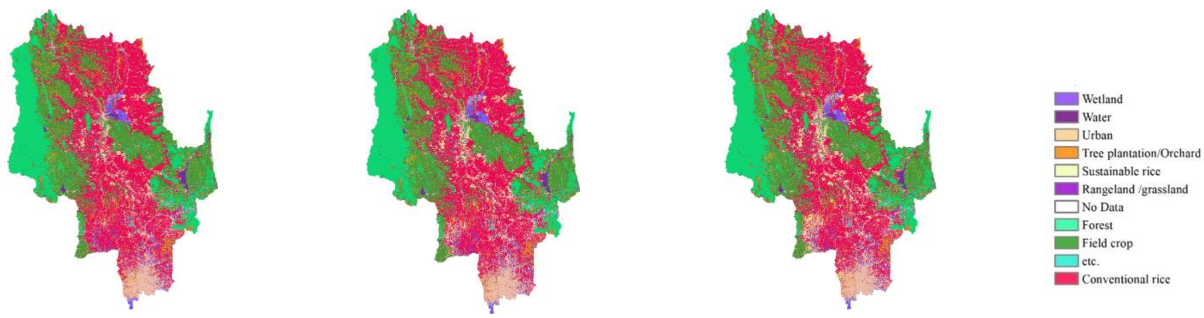
2030 **2040** **2050**



224,000 ha (2.65%) 336,000 ha (3.98%) 448,000 ha (5.31%)

Figure 3.2 Projected SRP rice area expansion in the NE of Thailand under BAU scenario.

2030 **2040** **2050**



96,000 ha (1.14%) 144,000 ha (1.71%) 192,000 ha (2.27%)

Figure 3.3 Projected SRP rice area expansion in the Central region of Thailand under BAU scenario.

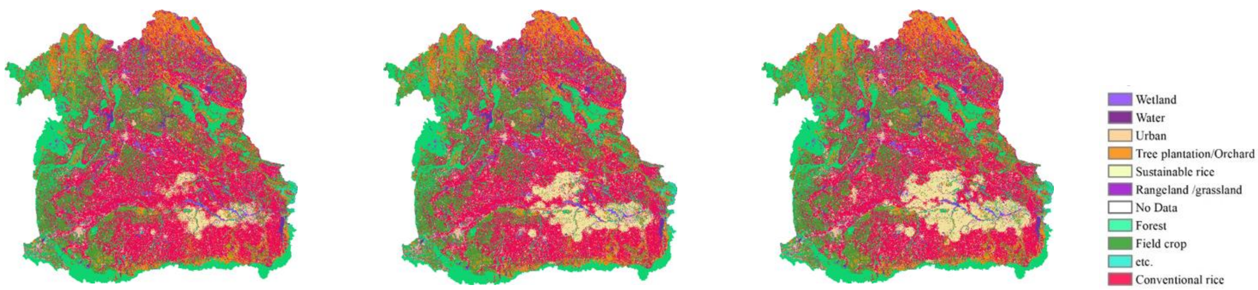
Note: For all scenarios projection maps, the number under each map indicates the projected area of sustainable rice in hectares, the number in parenthesis indicates the proportion of sustainable rice area to total rice area in the country.

Scenario 2: Moderate scenario assuming extension of MOAC strategy targets to 2050

Conventional rice to sustainable rice conversion improves but remains low. This scenario projects that sustainable rice practice area increases steadily at a realistic rate following MOAC's 20-year Agricultural and Cooperatives Strategy, which requires an annual transformation of conventional agricultural area of 650,000 rai (104,000 hectares) to sustainable agricultural area.

We estimate that 54% of this proposed expansion would be dedicated to rice farming, resulting in an increase in sustainable rice area of **350,000 rai (56,000 hectares)** every year. On this basis, the second scenario projects that sustainable rice will cover 11,000,000 rai (1,760,000 hectares) by 2050, which is about 20.84 percent of the country's rice production area. This is a substantial increase from 1.2 million rai (192,000 hectares) in 2022. Figures 3.4 and 3.5 visualize the pattern of transformation under scenario 2 in Northeast and Central regions, respectively.

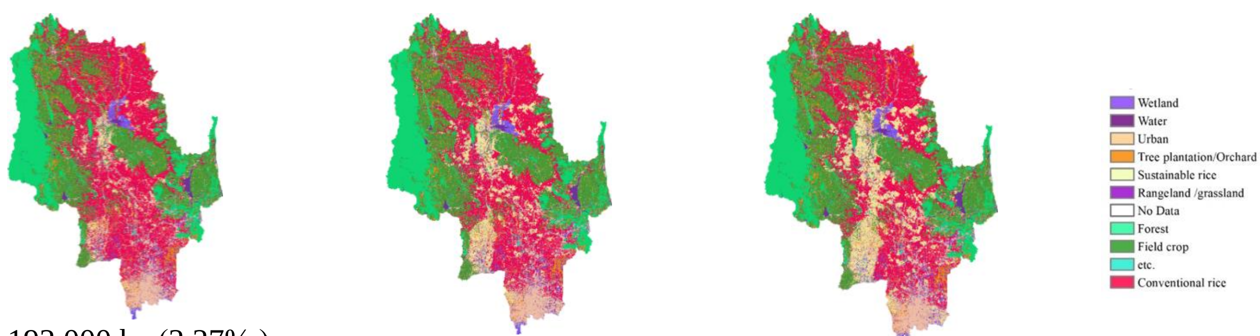
2030 **2040** **2050**



448,000 ha (5.31%) 840,000 ha (9.95%) 1,232,000 ha (14.59%)

Figure 3.4 Projected SRP rice area expansion in the NE of Thailand under scenario 2.

2030 **2040** **2050**



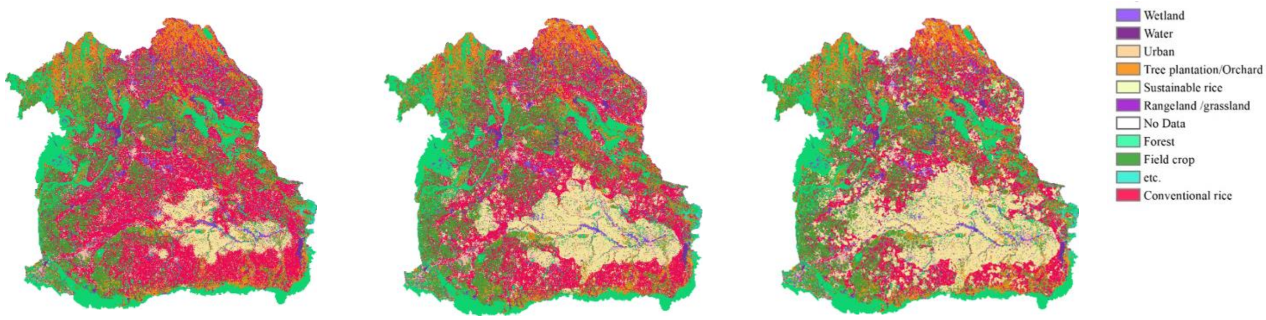
192,000 ha (2.27%) 360,000 ha (4.26%) 528,000 ha (6.25%)

Figure 3.5 Projected SRP rice area expansion in the central of Thailand under scenario 2.

Scenario 3: Enhanced scenario assuming extension of 13th National Plan targets to 2050

This scenario emphasizes Thailand's 13th National Development Plan's goal of increasing sustainable agricultural area by 4.5 million rai (720,000 hectares) by 2027. We estimate half of this growth would be dedicated to rice growing. In this scenario, sustainable rice practice is anticipated to increase by 1 million rai (160,000 hectares) each year from the 2022 baseline. This scenario would increase sustainable rice practice area to 29,200,000 rai (4,672,000 hectares) by 2050, accounting for 55.33 percent of the country's rice production area. Figures 3.6 and 3.7 represent the changes under scenario 3 in the Northeast and Central regions.

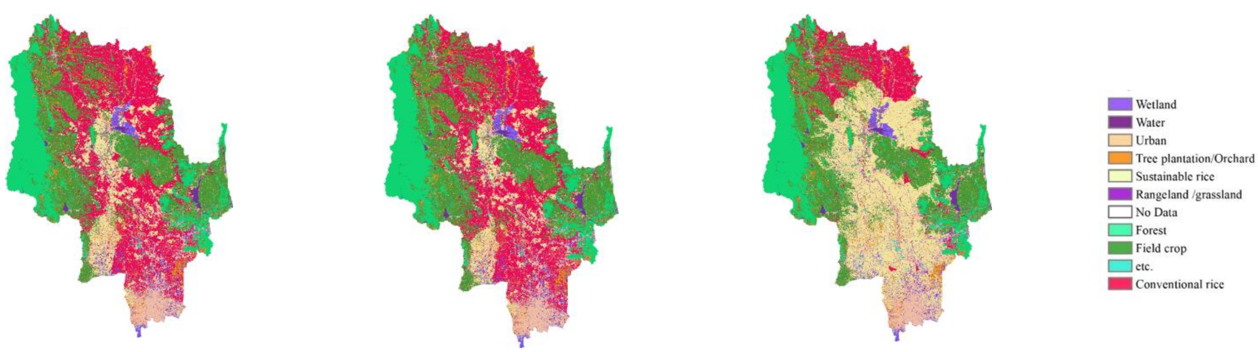
2030 **2040** **2050**



1,030,400 ha (12.20%) 2,150,400 ha (25.47%) 3,270,400 ha (38.73%)

Figure 3.6 Projected SRP rice area expansion in the NE of Thailand under scenario 3.

2030 **2040** **2050**



441,600 ha (5.23%) 921,600 ha (10.91%) 1,401,600 ha (16.60%)

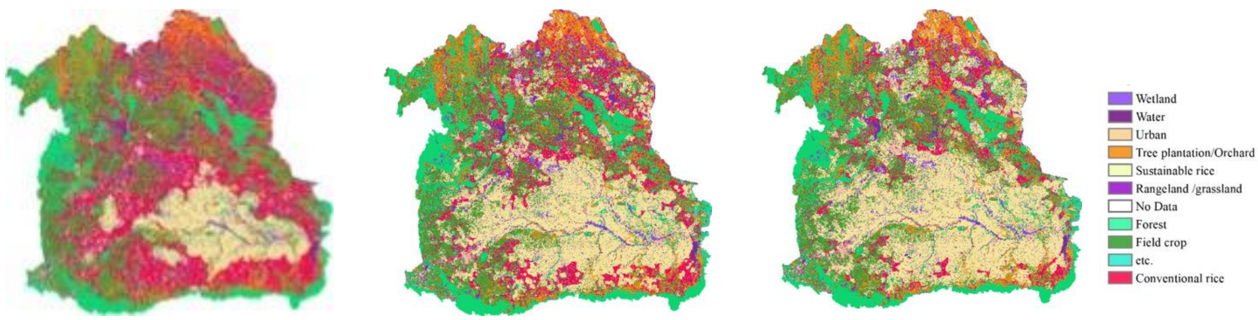
Figure 3.7 Projected SRP rice area expansion in the central region of Thailand under scenario 3.

Scenario 4: Transformational scenario assuming almost all rice areas are sustainable by 2045.

This scenario is based on the Thai parliament's determination in 2018 to adopt sustainable agricultural practices and to farm 149 million rai, or 100% of Thai agricultural land, sustainably by 2030, which requires 68 million rai. We assume that the government undertake extensive efforts to promote sustainable rice practice; yet, there are major structural hurdles to SRP rice conversion in the long run, which will prolong the conversion process beyond 2030, with about

two million rai (320,000 hectares) per year, achieved in 2045. Under this scenario, the total sustainable rice practice area for the NE and central region would reach on average 43.7 million rai (6,997,178 ha), accounting for 83 percent of the country's total rice production area by 2045 and remaining constant until 2050. Figures 3.8 and 3.9 visualize this transformation under scenario 4 of Northeast and Central regions, respectively.

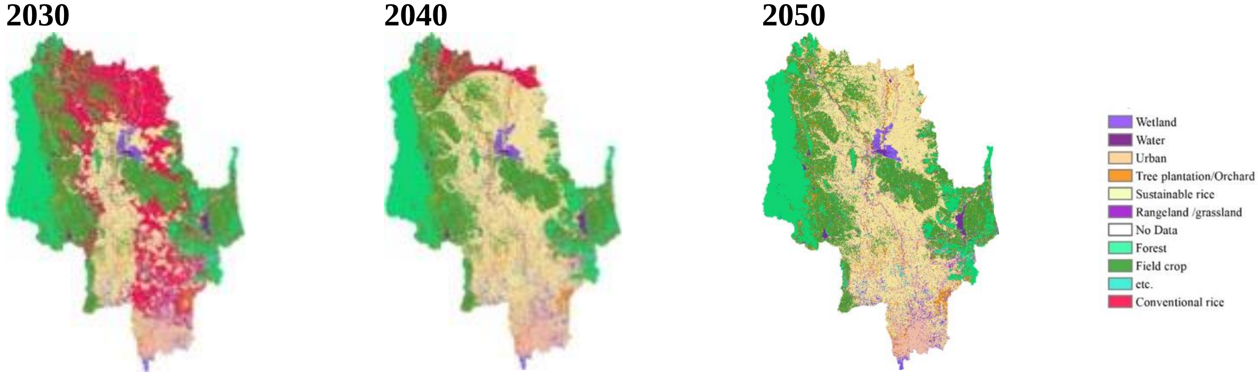
2030 **2040** **2050**



1,926,400 ha (22.81%) 4,166,400 ha (49.34%) 5,062,400 ha (59.95%)

Figure 3.8 Projected SRP rice area expansion in the NE of Thailand under scenario 4.

2030 **2040** **2050**



825,600 ha (9.78%) 1,785,600 ha (21.15 %) 1,934,778 ha (22.91%)

Figure 3.9 Projected SRP rice area expansion in the central region of Thailand under scenario 4

4. Summary of Changes Measured and Modelled

The land use area changes under each scenario are linked to measurable changes not only in rice output and revenue flows, but also changes to nature, people and society. 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 GHG emissions, and air pollution. Outcomes in terms of changes in human capital relate to changes in health of both farmers and the general public.

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 and sustainable agriculture policies. Impacts are assessed at the landscape level in terms of changes in the rice-field emission of greenhouse gases, air pollution, and the health impacts of chemical pesticides. Various biophysical and ecosystem services models, such as the Denitrification-Decomposition (DNDC) model and the Shannon-Wiener diversity index, are used in the analysis, applying locally available and field data, to project changes in natural capital, produced, human and social capital over the long term (2022-2050). Economic valuation methods are applied to quantify the true costs and benefits of different agricultural approaches in rice agroecosystems. A full outline of the methods and their details applied for each component of the analysis are included in the full findings report.

The research team conducted farming household surveys to identify relevant variables that differed between conventional and sustainable rice farmers. The main variables captured through this household survey included the processes of rice cultivation, the cost structure of rice cultivation, income from rice production, measures of social capital, demographic and socioeconomic data from each household. The rice farming households surveyed were statistically representative of farming households in the Northeast and Central regions. The areas studied included rainfed and irrigated areas.

4.1 Changes in rice production and income

One of the most visible and directly important impacts from sustainable rice practice cultivation on farmers and Thai economy are rice yields, revenues, and costs. Rice farmers, referred to as the backbone of the Thai economy, and key actors in the food security of the nation, face considerable economic constraints in Thailand, particularly in non-irrigated areas.

The TEEBAgriFood study generated modelling results using the Denitrification-Decomposition (DNDC) model to predict rice yields under conventional and sustainable rice practices over 2022-2050. This took into account the climate conditions projected by medium climate stabilization scenario (RCP4.5), including maximum, minimum and mean temperature, as well as average daily precipitation, for assessing changes to ecosystem services according to the four study scenarios outlined above. Annually predicted climate forecasts in the Northeast and Central regions of Thailand from 2022 to 2050 and current data on relevant climate ecological zones and soil series data from the Land Development Department were included in the parameters. Land and water management, rice residue management, and maximum rice production were taken into account. Key economic indicators of rice yield, farm income, and production costs were assessed and modelled.

A comparison of yields was undertaken in the Central and Northeast regions of Thailand to assess the yield related with various rice field management approaches. Additionally, the study examined seven management practices, consisting of two practices under condition of conventional rice (C1 and C2) and five practices under condition of sustainable rice (C3-C7). Their details are described as Figure 4.1.

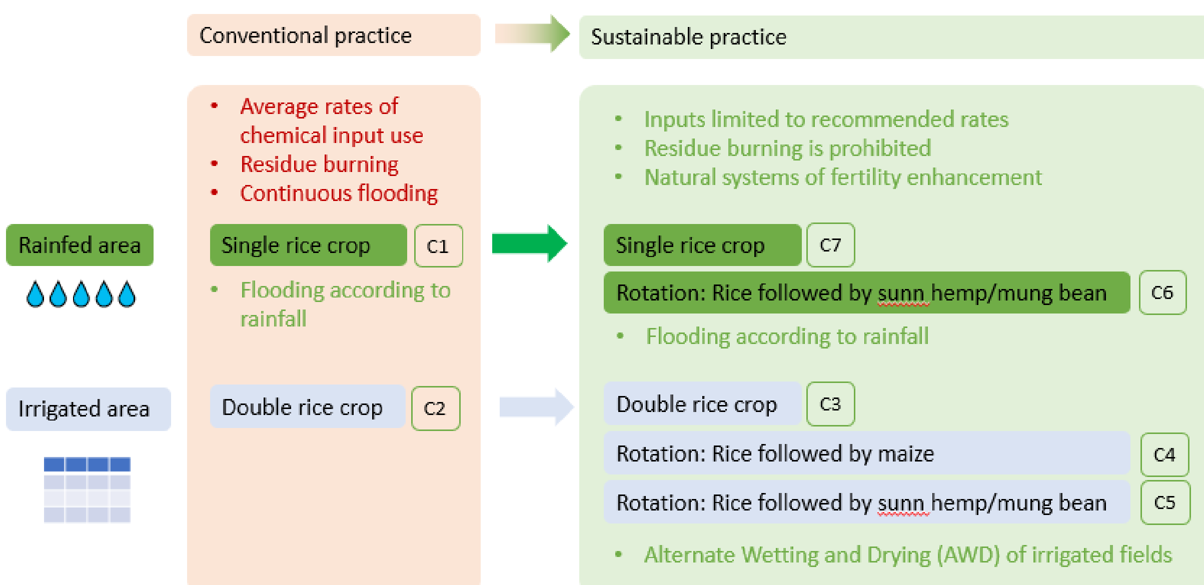
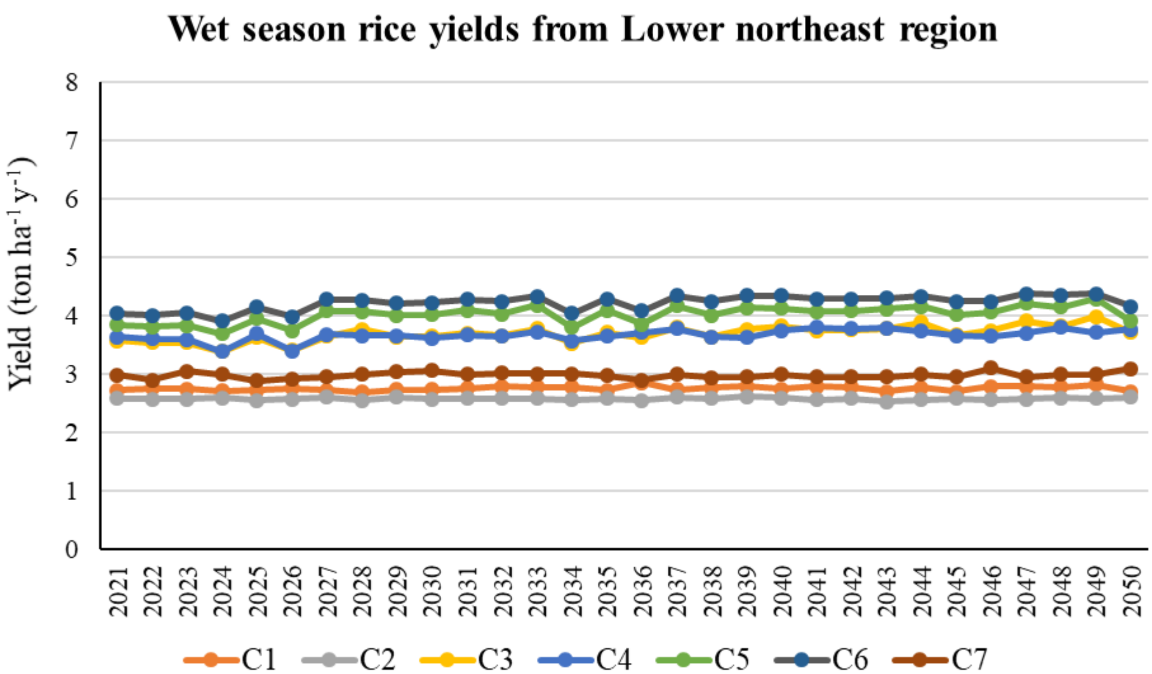


Figure 4.1 Assumptions about switch of rice practices in areas with and without irrigation

The results from the models suggested that rice yield in the Central and Northeast regions of Thailand fluctuates based on the specific year's climate conditions and the management practices employed in a given year. When focusing on regions, rice yields in the Central region are higher compared to those in the Northeast region. Retaining crop residues within the soil through sustainable rice practice management contributes to the preservation of soil organic matter. The inclusion of sunn hemp in the sustainable rice practice management would result in improved yields in both regions, despite a decrease in fertilizer usage (Figure 4.2-4.4).



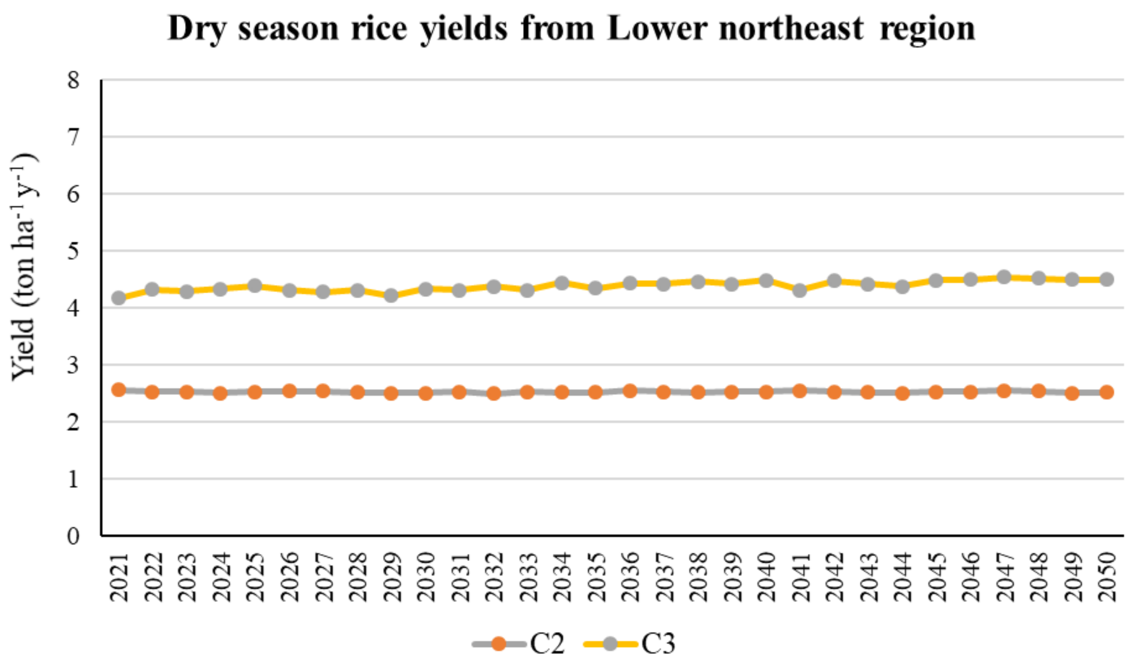
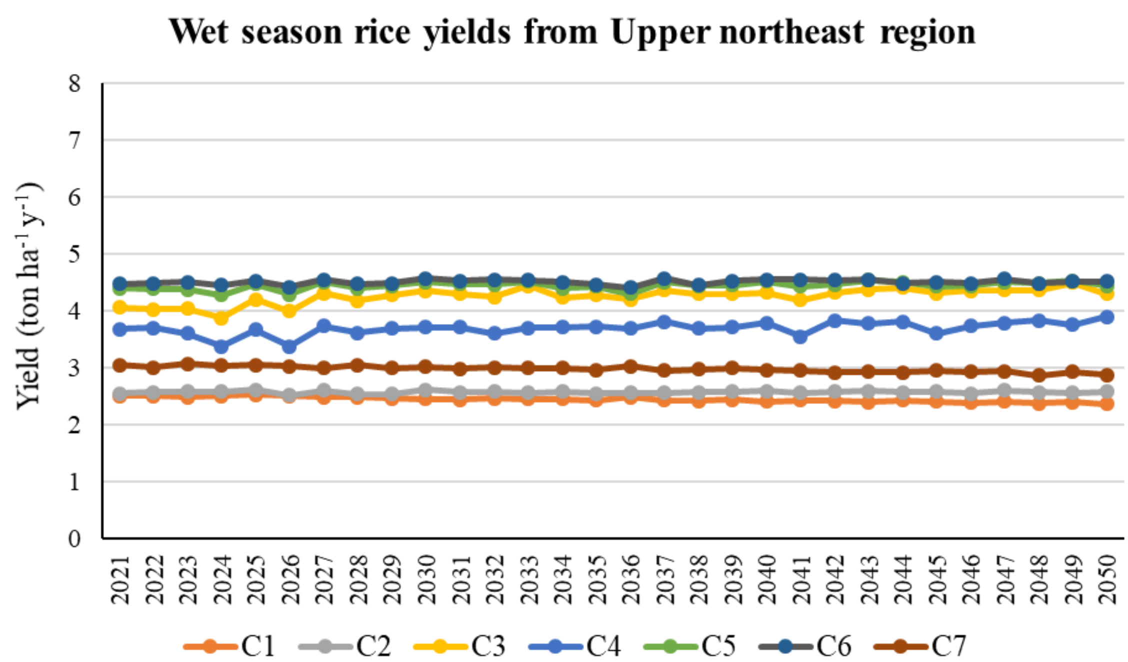


Figure 4.2 Rice yields from seven practices over 2021-2050 in lower northeast region



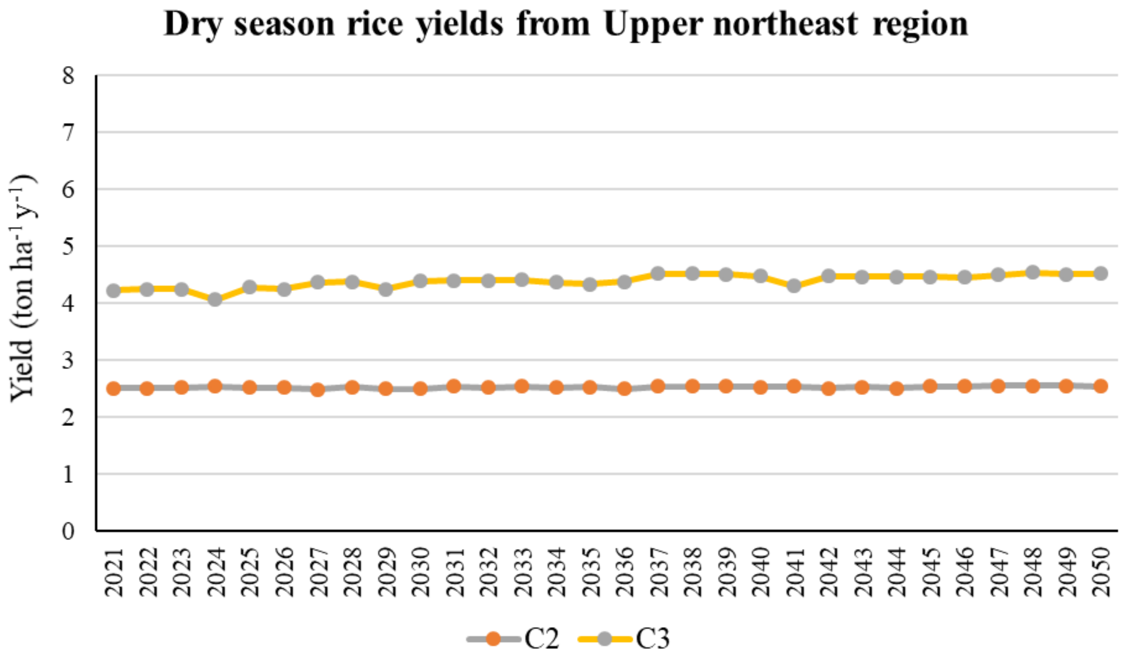
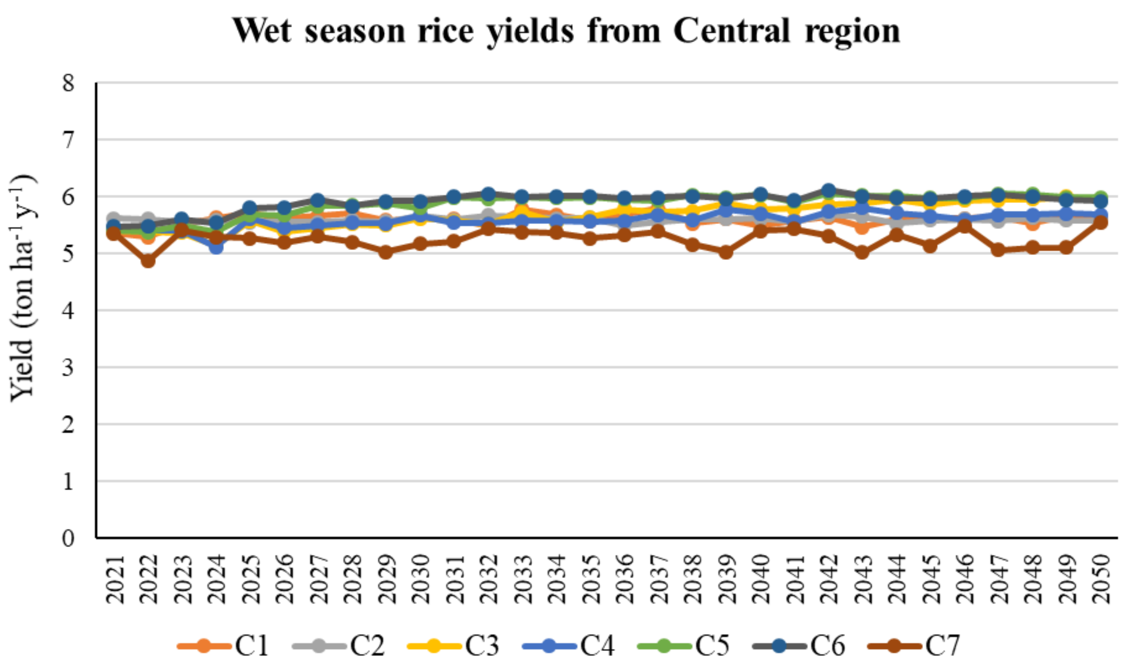


Figure 4.3 Rice yields from seven practices over 2021-2050 in upper northeast region



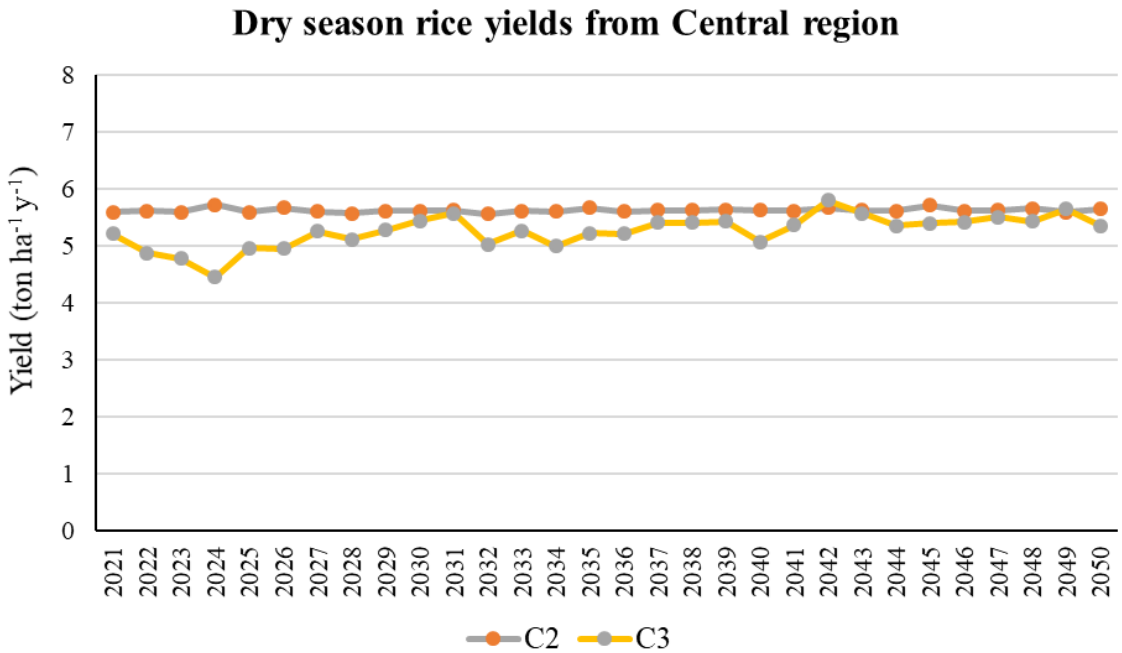


Figure 4.4 Rice yields from seven practices over 2021-2050 in central regions

The cultivation costs of conventional and sustainable rice practices were analyzed by field data collected from both types of farmers. The data reveals that the cost structure of both practices is similar. However, the conventional rice practice requires higher overall costs than sustainable rice practice. The lower cost of sustainable rice practices compared to conventional rice practice is mainly generated from the lower cost of chemical fertilizer. In addition, the sustainable rice practice in the Northeast region contains lower cost of labor than conventional rice practice.

The combination of lower cost of production and better yield of sustainable rice practice suggests that sustainable rice practices would generate more profit per hectare to farmers than conventional rice practice.

4.2 Environmental Externalities – Changes in natural capital

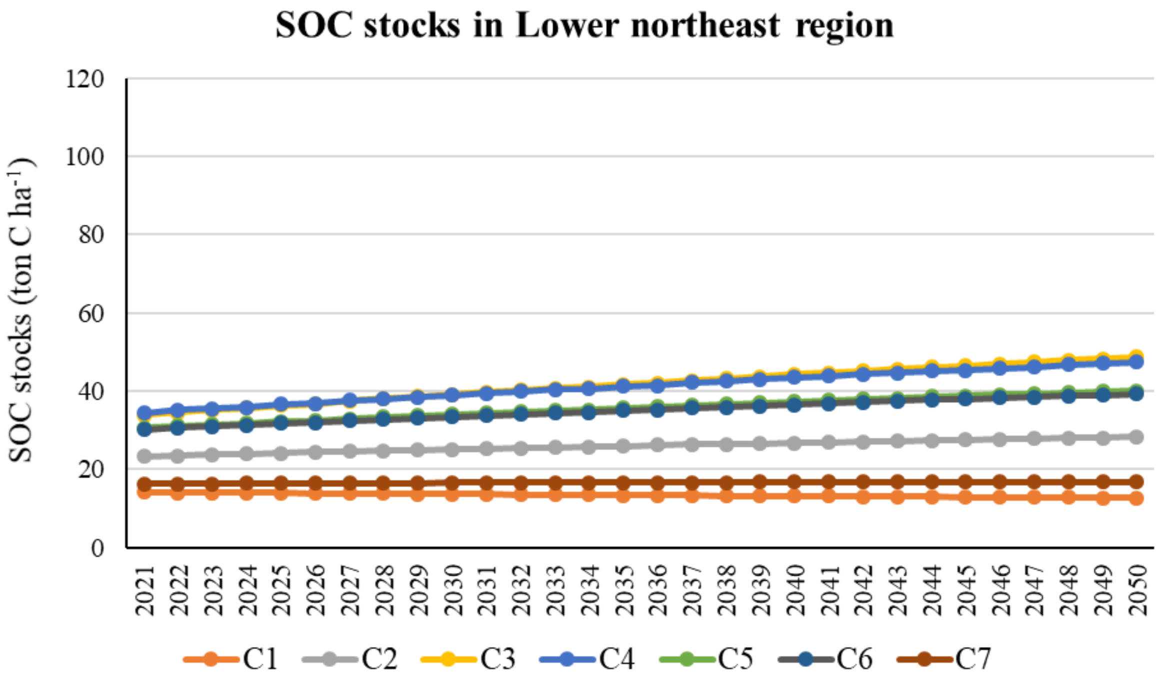
Greenhouse gas emissions

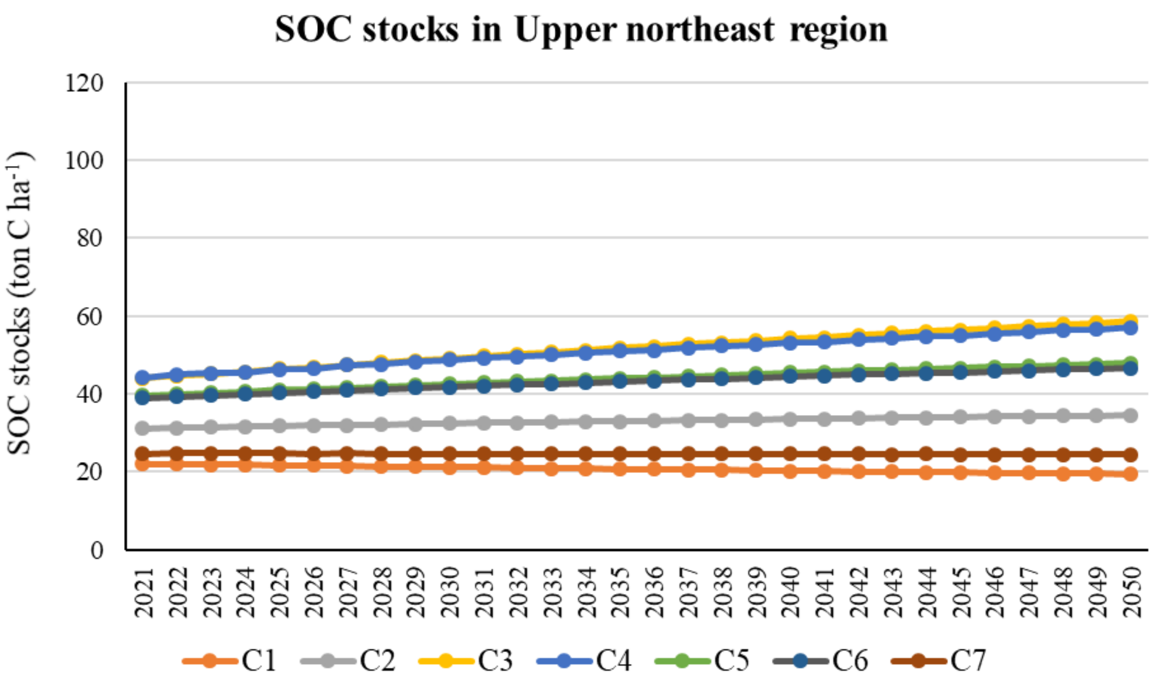
Rice cultivation plays an important role as both a significant reservoir for capturing carbon dioxide and an origin of emissions. The notable greenhouse gas (GHG) emissions during rice cultivation are methane (CH4) from the fermentation of organic matter under flooded field conditions, nitrous oxide (N_2O) from fertilizer application, and various GHGs from rice straw burning.

Regarding GHG emissions during the cultivation stages of double rice cultivation where rice is cultivated twice a year in irrigation area in the Central and Northeast regions of Thailand, it has been observed that sustainable rice practices result in lower GHG emissions compared to conventional rice practices. Specifically, the findings indicated that sustainable rice practices lead to an average release of 6.64 and 11.00 tons of CO_2 equivalent per hectare per year in two regions, while conventional rice practices result in an average emission of 8.82 and 13.35 tons of CO_2 equivalent per hectare per year, respectively.

However, if only one crop of rice is grown, then sustainable rice practices lead to an average release of 2.85 and 6.24 tons of CO_2 equivalent per hectare per year in the Central and Northeastern regions, respectively. Conversely, conventional rice practices result in an average emission of 1.54 and 3.17 tons of CO_2 equivalent per hectare per year in the respective regions.

In the context of soil carbon sequestration, this study has revealed that sustainable rice practices lead to an enhancement in SOC stocks when compared to conventional rice practices. The average SOC stocks resulting from sustainable rice practices in the Central and Northeast regions of Thailand, under single rice cultivation, amounts to 49.47 and 20.59 tons of carbon per hectare. In contrast, conventional rice practices in the same regions produce average SOC stocks of 42.34 and 17.03 tons of carbon per hectare. When considering double rice cultivation in the Central and Northeast regions, sustainable rice practices exhibit higher levels of SOC stock compared to conventional rice practices. The findings demonstrate that sustainable rice practices contribute to SOC stocks of 86.24 and 46.73 tons of carbon per hectare in these regions respectively. Conversely, conventional rice practices result in average SOC stocks of 75.70 and 29.45 tons of carbon per hectare, respectively (Figure 4.5).


SOC stocks in Lower northeast region
SOC stocks (ton C ha-1)
120
100
80
60
40
20
0
2021 2022 2023 2024 2025 2026 2027 2028 2029 2030 2031 2032 2033 2034 2035 2036 2037 2038 2039 2040 2041 2042 2043 2044 2045 2046 2047 2048 2049 2050
C1 C2 C3 C4 C5 C6 C7


SOC stocks in Upper northeast region
SOC stocks (ton C ha-1)
120
100
80
60
40
20
0
2021 2022 2023 2024 2025 2026 2027 2028 2029 2030 2031 2032 2033 2034 2035 2036 2037 2038 2039 2040 2041 2042 2043 2044 2045 2046 2047 2048 2049 2050
C1 C2 C3 C4 C5 C6 C7

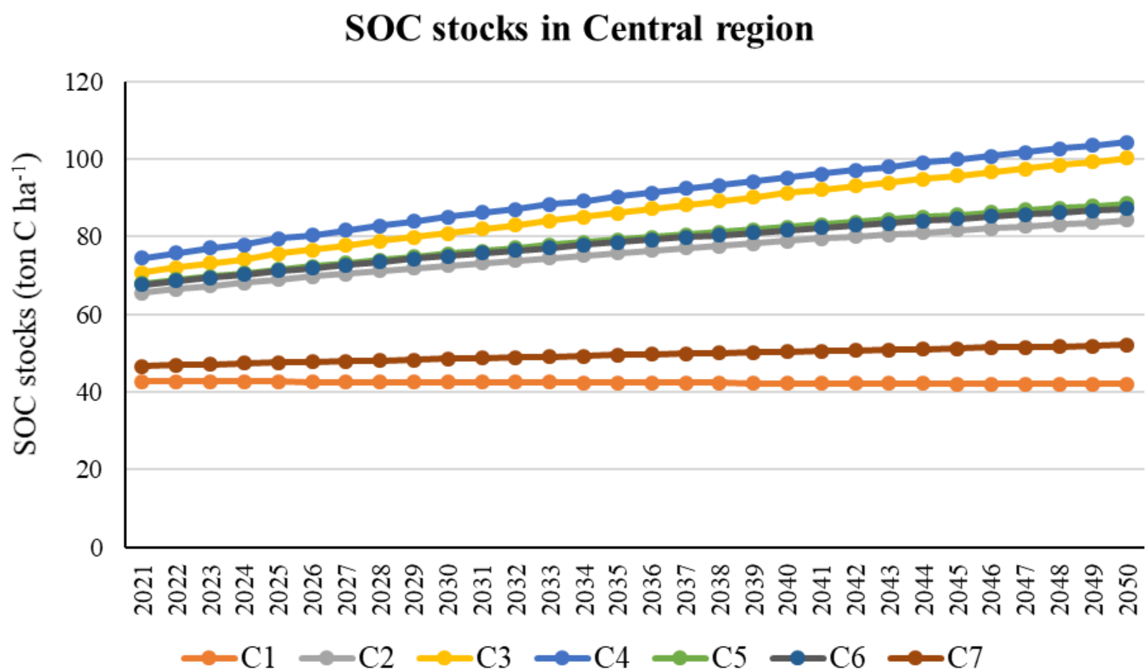


Figure 4.5 SOC stocks of topsoil from different rice practices over 2021-2050 in lower northeast, upper northeast, and central regions

Considering the overall balance of emissions and sequestration, sustainable rice practices result in lower remaining GHG emissions after offsets when compared to conventional rice practices. In addition, all of these measures are analyzed at landscape level in scenario analysis to identify the effect of expanding the sustainable rice area on GHG emissions, which are presented in section 5.

Water use in rice cultivation

Rice is among many cash-crops that consume a large amount of water. The research team analyzed water supply, water quality and water footprint in sustainable and conventional rice cultivation practices in the Central Plain and the Northeast of Thailand. The purpose of this analysis is to measure and value hydrological ecosystem services, which would be provided differently in the future under alternative scenarios.

Ecological processes that help maintain hydrological ecosystem services are directly influenced by land use and land management practices in combination with other factors such as basin topography, soil properties and rainfall characteristics. Water supply depends on climatic conditions, which to a certain degree is associated with forestlands. Averaged rainfall and stored runoff water in the Northeast's major river basins (i.e, Kong, Chi and Mun) are approximately 1,246.04 mm/year and 253.44 mm/year, respectively. Meanwhile, the Central Plain receives smaller amounts of rainfall, but a depth of runoff is higher. The Northeast's geology is primarily based on sandstones - soil parental matter; thus, a typical soil texture in the region is sandy soil. The sandy soil obtains low capability of storing water. The abundant rain sinks quickly through the porous soil that plants find very little water available in the surface layer.

Water parameters in the selected paddies are within Thailand's water quality standard. Concentration levels of total phosphorus are not significantly different across all the study sites, cultivation practices and planting methods. This illustrates non-effect of phosphorus (P) accumulation in water due to high solubility of P-based fertilizers, resulting in a short transferring time period from water to accumulating in soil. On the other hand, nitrate (NO_3^-) concentrations were significantly different across the study sites in the Central Plain. This depicts an excessive use of N-based fertilizers, resulting in large amounts of nitrogen deposition particularly in surface water. Moreover, levels of pH, electrical conductivity, salinity, turbidity, and total dissolved solids in water samples from the conventional rice practice (CON) and sustainable rice practice (SRP) in both regions fluctuated depending on soil characteristics, climatic conditions and amounts of chemical fertilizers applied in rice paddies.

Rice cultivation under the SRP does not demonstrate better water quality. In fact, amounts of NO_3^- were higher than water samples from the CON. Therefore, to examine concerns about nitrate pollution in water arising from rice production, a grey water footprint (WF_{grey}) was measured by estimating the amount of water required to dilute NO_3^- from rice field runoff to a natural level. Amounts of WF_{grey} differ depending on cultivation practices: SRP vs. CON, seasons: rain-fed vs. irrigated rice cultivation, and planting methods: transplanting vs. direct sowing; because they determine farm maintenance practices, especially fertilizer application. Although we observed mixed findings across all the study sites, the SRP with the rain-fed rice cultivation and the direct sowing method reveals smaller sized WF_{grey} due to higher yields. This confirms the SRP benefit, especially on yield improvement.

Finally, a total water footprint is an indicator of the human use of water, including green, blue and grey water footprints. A footprint size in agriculture is usually expressed in water volume per mass – m^3/ton, which is equivalent to liter/kg. The size of water footprints depends on amounts of rice yields. Higher yields will result in smaller footprints. To estimate the crop water requirement: the water needed for evapotranspiration under ideal growth conditions, a CROPWAT 8.0 (the USDA SCS method) was employed. Rice cultivation in the Central Plain depends more on irrigation water, whereas the Northeast relies more on rainwater. The Central Plain obtained significantly greater amounts of rice yields (5.79 tons/ha) than the Northeast, making their water footprints significantly smaller than the Northeast's footprints. Moreover, the SRP obtained greater yields, resulting in smaller green, blue, and total water footprints in both Northeast and Central regions when compared to the CON practice. Therefore, sustainable rice practice yields better water use efficiency than that of conventional rice practice in both regions.

Biodiversity in rice field: Insect diversity

In Thailand, rice fields dominate the landscape. Field conditions alter rapidly, in part due to management practices, and the transient habitats that are generated support an abundance of biodiversity. Rice fields house an array of organisms, including fish, amphibians, insects, and plants, that contribute to food, medicine, and ecological balance. However, conventional practices involving chemicals and field residue burning pose threats. Transitioning to avoiding as much as possible the use of agrichemicals methods and understanding landscape relationships are becoming crucial for preserving this biodiversity. The research team assessed insect and vegetation diversity in rice fields under different farming practices, highlighting the intricate interplay between agriculture and ecosystems.

The study encompassed 84 sampling sites across Thailand's Northeastern and Central regions, investigating insect diversity in both conventional and sustainable rice farming (SRP) practices. The team assessed pooled insect biodiversity[5] and discovered interesting patterns at a landscape scale. The analysis indicates that SRP supports higher level of biodiversity of insect within both Northeast and Central region, but vary between regions and functional groups of insects (predators and pest).

[5] using rarefaction curves to estimate species richness, beta diversity, Shannon, and Simpson diversity indices by combining samples from both practices, mitigating sample size and environmental biases.

The Northeast demonstrated higher species richness in conventional rice farming but greater Shannon and Simpson diversity indices in SRP, clearly indicating SRP's superiority in fostering a diverse, balanced ecosystem.

Conversely, the Central region showcased higher species richness and beta diversity in SRP farming, while conventional farming exhibited greater Shannon and Simpson diversity indices. In general, it appeared that conventional rice farming yield higher diversity of insects than the SRP. However, an investigating functional groups like predators and pests revealed complex relationships within this region. The SRP showed greater species richness for predators and pests, and higher Shannon/Simpson indices for predators. These results suggest that the SRP in the Central region supports a higher diversity of predatory insects that benefit pest control (as reflected by lower diversity of pests in SRP). This pest and predator interaction demonstrated a potentially enhanced predator-prey relationship in the Central region’s SRP farming.

These outcomes accentuate regional variations in biodiversity patterns, emphasizing the contextual impact of choosing between conventional and SRP practices which is also influenced by other landscape variables i.e., bioclimatic, land use patterns and appearance of a specific habitat like wetlands. These results deepen our understanding of ecological dynamics, highlighting sustainable practices’ potential for pest management and agricultural sustainability.

Biodiversity in rice field: Trees on farm

This section investigates patterns of agroforestry (trees on farm) in rice cultivation across regions and practices (conventional rice practice vs. sustainable rice practice). While no significant connections between tree presence and yields or water use are apparent, agroforestry, specifically “trees on farm”, add on tangible and intangible benefits to the rice agroecosystem landscape and farmer household, including biodiversity conservation, household food supply, income generation, and local climate regulation. The sustainable rice practice demonstrates greater tree densities and vegetative diversity than the conventional counterpart, particularly in the Northeast, including the total tree density, the native tree density, and the diversity of total trees and of native species. Keeping native trees or planting new trees on farms, including trees for food and income, can be observed throughout the Northeast. This practice helps protect trees, maximize the use of land and maintain local livelihoods.

4.3 Health Externalities – changes in stocks of human capital

Health cost caused by PM2.5

The study examined the effects of pesticide poisoning and air pollution on human health in relation to human capital, specifically in conventional and sustainable rice cultivations. The environmentally concerned practice of SRP rice cultivation strictly prohibits the burning of rice straw and residue in open fields for the entire production process. The transition from conventional to sustainable rice cultivation practices can have a positive impact on the air quality for the public. Consequently, in this study, it is presumed that the origin of residue burning in rice fields does not stem from the sustainable rice practice zone. As a result, the conventional rice production area becomes a potential contributor to residue burning, and this will be utilized to gauge the health cost associated with rice production.

To monetarize the impact of rice straw open burning on local air quality in the NE and central of Thailand, the concept of human capital of public health is applied. The concept of human capital method in public health is being applied to assess the economic impact of rice straw open burning on air quality in the northeast and central regions of Thailand. Firstly, open rice field burning is employed to evaluate the practice of rice residue burning. The methodology introduced by Junpen et al. (2018) enabled the study team to forecast alterations in health impacts arising from the exposure to PM2.5 emissions due to transitions in land-use. The burning scenarios are based on the transition of conventional rice production to sustainable rice practice production. The human impact assessment relies on the Amended Human Capital approach (AHC), which calculates expenses in relation to the societal loss of productivity. This method considers individual work absences, adjusted by the per capita gross domestic product, corresponding to the specific health effects being studied. The AHC approach is widely employed to appraise the reduction in human capital due to air pollution, operating under the assumption that human capital constitutes the collective contribution to society (Huang et al., 2012; Yin et al., 2015; Yin et al., 2017). The economic value stemming from the health risks associated with exposure to PM2.5 emissions originating from rice straw burning in the year 2021 was calculated to be 12.76 USD per hectare in the NE region and 512.90 USD per hectare in the central region of Thailand.

Health cost caused by pesticides

While the use of pesticides in rice cultivation increases productivity, it also leads to higher health risks for people as pesticide concentrations in the environment increase. Especially for farmers who are directly exposed to pesticides. Not only farm workers who spray pesticides, but also those who mix and load the pesticides, sow pesticide seeds, weed and harvest sprayed crops, and clean and dispose of the containers (Tago et al., 2014).

Based on our survey of 728 farm households in the central and northeastern region, we divided the sample households into two groups based on their farming practices: 376 households with Sustainable Rice practice (SRP) and 352 households with conventional practice. We found that the pesticides most commonly used by the farmers surveyed could cause symptoms such as nausea, vomiting, chest tightness, malaise, decreased urination, kidney failure, lung swelling, itchy rash, skin irritation, toxicity, and pulmonary fibrosis. Prolonged exposure to this substance has also been associated with Parkinson's disease. Some substances can cause severe nerve irritation and easily lead to death (Sangchom, 2013). Measured by the average expenditure on pesticides per hectare, the amount of pesticides used in SRP was less than half of the amount used in conventional practice. The difference ranged from 5% to 78% of the average expenditure.

In our survey, each household was asked about the incidence of illness caused by chemicals used in rice fields. Only 88 households reported that their members' health was affected by pesticide use, including 9.6% of SRP households and 14.8% of conventional households. A statistical test showed a significant difference between the two proportions at a 5% significance level. The 10 common symptoms associated with cultivation included headache, eye irritation, skin irritation/burns, fever, diarrhea, allergies, sore throat, joint pain, nausea, and muscle twitching/pain. Both household groups had the same proportion of each symptom. Joint pain was the most commonly reported symptom among sampled households, followed by headache and fever. Nevertheless, none of these symptoms were fatal or chronic health effects.

To monetize the impact of pesticide on health of farmer, cost of illness (COI) and defensive expenditure (DE) concepts 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 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. However, the cost of illness and defensive expenditure may not capture all health effects. As the chronic health effects may not be observed in such a small sample, we attempted to evaluate potential chronic impacts using the benefit transfer method.

The estimated total health costs for each group are summarized in Table 4.1 Although the costs of illness of SRP group is lower, together with the defensive cost, the health cost of SRP farmers is slightly below that of conventional farmers. With a similar average cultivated area of 3.4 ha, the average health costs per area for SRP farmers and conventional farmers are 1,225.67 and 1,268.13 baht per ha, respectively.

However, our health care costs may be underestimated because the illnesses in our study were based on self-report. In a previous study, few cases of pesticide poisoning resulted in medical care (Lee et al.; 2012). Most farmers may only think about the short-term effects of acute poisoning and not the serious illnesses that can be caused by chronic pesticide exposure. Some farmers also consider poisoning symptoms as "normal" and do not pay much attention to them (Bourguet, D., & Guillemaud, T., 2016). In addition, fatal cases of pesticide exposure were not included in the survey study because it is difficult to estimate the number of cases directly attributable to pesticide exposure and because survey studies, by definition, cannot account for fatalities (Bourguet, D., & Guillemaud, T., 2016).

The benefit transfer method can be used to estimate the monetary value of chronic health effects based on previous literature. Several studies found that the estimated cost of chronic pesticide exposure limited to cancer was at least four times greater than the estimated cost of acute poisoning events (Pimentel (2005, 2009); Pimentel and Burgess (2014)). According to this method, health costs including chronic effects are 1,693.54 baht/ha and 1,907.58 baht/ha for SRP and conventional respectively. However, the values from this method should be used with caution. The benefit transfer method has the disadvantage that the costs could not be comparable because they are influenced by several factors, such as the type of pesticide used, the number of treatments, the degree of protection of the farm personnel spraying the pesticides, etc., which can vary greatly from country to country.

Table 4.1 The estimated health cost from survey by cultivation practice

Costs (units)	Sustainable Rice Practice (SRP)	Conventional Practice (CON)
Health cost (bath/ household/ year)		
Cost of illness	397.69	543.53
Defensive expenditure	3,769.60	3,768.10
Total	4,167.29	4,311.63
Total cultivated area (ha/ household)	3.4	3.4
Non chronic exposure health cost (baht/ha)	1,225.67	1,268.13
Chronic exposure health cost (baht/ha)	467.87	639.45
Total health cost (baht/ha)	**1,693.54**	**1,907.58**

4.4 Social capital

This study also assessed differences in social capital between conventional and organic rice farmers. Changes in social capital were explored through a qualitative analysis of the results of the household survey. The happiness, social ties, and social network of conventional and SRP practices were examined. Data from household survey presents that farmers who practice sustainable rice practice would likely be happier than conventional rice farmers. When considering the factors that would drive the happiness of farmers, family and income are the first and second variables that determine the happiness level of both types of farmers.

We also analyzed the social ties situation of sustainable rice and conventional rice farmers. The results from our analysis suggest that generally sustainable rice farmers seem to have higher social ties than conventional counterpart especially for voluntary activity. In addition, female sustainable rice farmers seem to participate more in the farmer groups than female conventional rice farmers. The degree of participating in the groups between female and male sustainable rice farmers is the same, while the female conventional rice farmers participate in the groups less than male conventional rice farmers.

For social network, our results suggest that social network between conventional rice farmers and sustainable rice farmers are very similar in terms of size of social network and characteristics of the nodes who are defined as the center of network. In addition to this finding, we also found that besides receiving information and observing from the nodes for new agricultural practices, farmers also receive information and follow the guidance regarding to the new agricultural technology from their relatives and close friends. These findings of social network study would be a starting point to the way of using social network information to select farmers who would be trained as early sustainable rice adopters. They could then spread information and lead others in their network to adopt sustainable rice practice.

5. Valuation and Scenario Analysis

The cost benefit analysis was conducted to analyze net benefit of all impacts from switching conversional rice to sustainable rice practice based on scenarios in term of money value. The quantified impacts including income of rice production, cost of rice cultivation, health impacts, and greenhouse gases emissions were monetized to calculate relative benefits and costs between conventional and sustainable rice practices.

Even though this study explores the differences of social capital and biodiversity measured by trees on farm between conventional rice and sustainable rice practices, these two measures are not included in the benefit-cost analysis. This is because, for the social capital, the measurement is qualitative in nature. It is therefore difficult to identify appropriate financial proxy to monetize it. For the trees on farm, though the study quantified the differences in the number and variety of tree species between these two practices, it could not clearly clarify causation. Namely, this study cannot indicate that higher number of trees on farm and more variety of tree species on sustainable rice practice farm are the results from adopting sustainable rice practice.

Moreover, results on water use, an important input for rice cultivation, could not been accounted for in monetary value. The research team were unable to develop a value for the opportunity cost of water in a context of water scarcity in the two regions. Water efficiency in terms of rice production (kilogram) per cubic meter of blue and gray water is reported to shed light on comparative efficiency of water use for the two rice practices.

Financial proxies for monetisation of results over time

The study applied the following set of financial proxies to illustrate the magnitude of changes in value (gains and losses) over time, as more and more of Thailand's rice area is converted to sustainable rice cultivation methods. These proxy costs are summarized in table 5.1 below.

Rice prices applied in the analysis

The prices of rice output were identified as a value change based on scenarios. Differences in rice output over time were converted into a monetary figure using regional proxies, reflecting the predominant rice varieties in each region. The proxy used for the value of the rice output in the Northeastern region was the average farmgate price of the premium rice variety, Hom Dok Mali. The proxy used for the value of rice output in the Central region, was the average farmgate price of white rice, the proxy proposed are $374.59 and $235.40 /ton of rice output, respectively.

Costs of production applied in the analysis

There is currently no standard premium per ton of sustainable rice at the mill. Although there are some farmers in Ubon Ratchathani province where this is being financed by rice through project support. Therefore the price of rice applied to the output from sustainable rice practice in this study is the same as for conventional rice. However, based on survey information, sustainable rice practice involves less production cost than conventional rice practice, in particular saving land preparation and fertilizer costs in the Central region, and savings from pesticide and fertilizer costs in the Northeast region.

Health impact proxy values applied in the analysis

The impact on human health were captured by two effects. The first one was from the impact of PM2.5 on public health estimated based on Exposure-response function model depending on scenarios. The second impact was health cost from pesticide on farmers' health calculated by the defensive expenditure approach. The sustainable rice practice could save the farmers' health cost from pesticide about $38.22 per hectare based on value approach. The PM 2.5 health cost is direct monetary values depending on reduction of burning area from sustainable rice practice in each scenario.

GHG emissions reduction proxy values that were applied in the analysis

Finally, the value of reduced GHG emissions was represented as an average carbon credit value. The median value applied was based on the average closing spot prices of European Emission Allowances (EUA) from 2019 to 2022) approximately $38.19 per ton of CO2eq. Given that the price of carbon credits continues to change over time, and are traded at different prices in different markets, the research team considered two alternative prices for a sensitivity analysis. These included the carbon credit price applied in the voluntary market established by the Thailand Greenhouse Gas Management Organization (TGO), which is approximately $5 per ton of CO2eq. This can be considered a low-bound value. The team also assessed GHG emissions reduction using the "social cost of carbon", as proposed by the US EPA at $51 per ton of CO2eq. This value is undergoing review for the appropriateness of adopting this as an international standard value for carbon emissions reductions going forward.

Table 5.1 The monetary proxy per unit of factors

Variables	Monetary Proxy	Unit	Value (Northeast region)	Value (Central region)
Rice production	Rice price	$/ton	374.59	235.40
Cost of production	Cost	$/hectare	21.56	55.38
Health cost from PM2.5	PM 2.5 Health cost	$/year	Cost	Cost
Health cost from pesticide	value approach	$/hectare	38.22	38.22
GHG emission (EU Emissions Trading System)	Carbon Price	$/ton of CO2eq	38.19	38.19
GHG emission (Thailand Greenhouse Gas Management Organization price)	Carbon Price	$/ton of CO2eq	5	5
GHG emission (US EPA)	Social cost of carbon	$/ton of CO2eq	51	51

Scenario analysis results

The area changes from conventional to sustainable rice practice were compared based on 4 scenarios, BAU, S2, S3, and S4, which were converted to net present values (NPV) with a 5 percent discount rate, from year 2022 to 2050. The NPV presents the accumulated change in benefits and costs generated in the BAU scenario. This is used as a reference value to measure and compare the projected changes in scenario 2, scenario 3, and scenario 4. Figures 5.1 and 5.2 in the northeast and central regions illustrate the maximum extent of the expansion of sustainable rice practice area in each scenario by 2050 where the sustainable rice practice areas are 640,000 hectares, 1,760,000 hectares, 4,672,000 hectares, and 6,997,178 hectares under BAU, S2, S3, and S4, respectively.

Figure 5.1 Sustainable rice practice area expansion in the Northeast region for each scenario by 2050

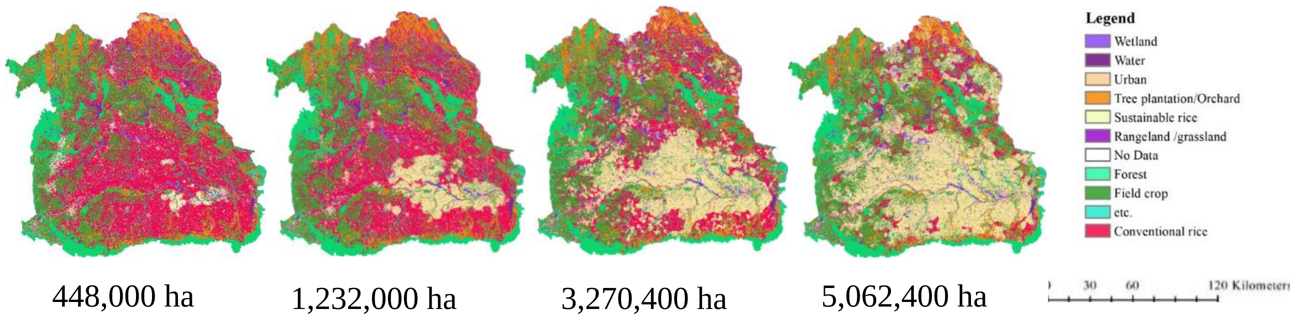
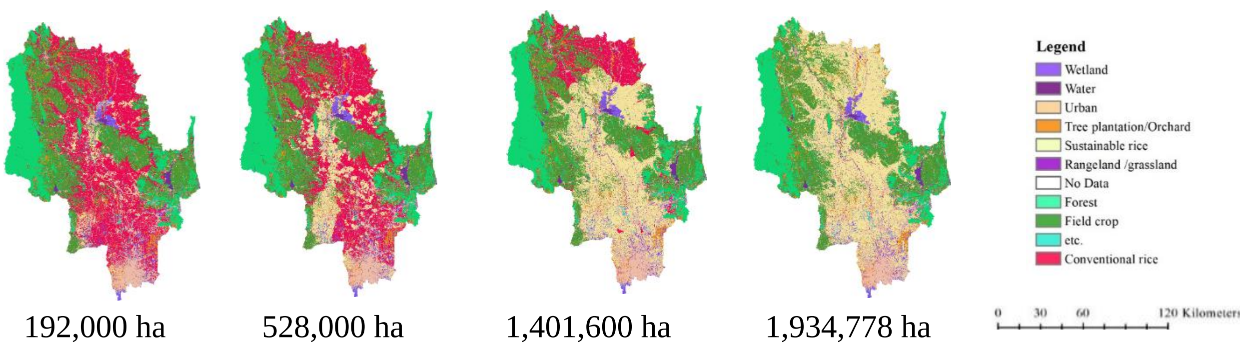


Figure 5.2 Sustainable rice practice area expansion in the Central region for each scenario by 2050



In each scenario, the benefits or losses between the two rice practices were calculated based on the different value of three conditions. The first condition assumes double crops of rice per year in the irrigated area and single crop of rice per year in non-irrigated area (*rice only*). The second condition is a single crop of rice per year in both irrigated and non-irrigated areas in rainy season, while during the dry season, farmers in irrigated area grow maize, later called *rice followed by maize*. The last condition is one crop of rice per year as well, but both in irrigated and non-irrigated rice areas grow sunn hemp during dry season, later called *rice followed by sunn hemp*.

5.1 The scenario analysis: Country perspective

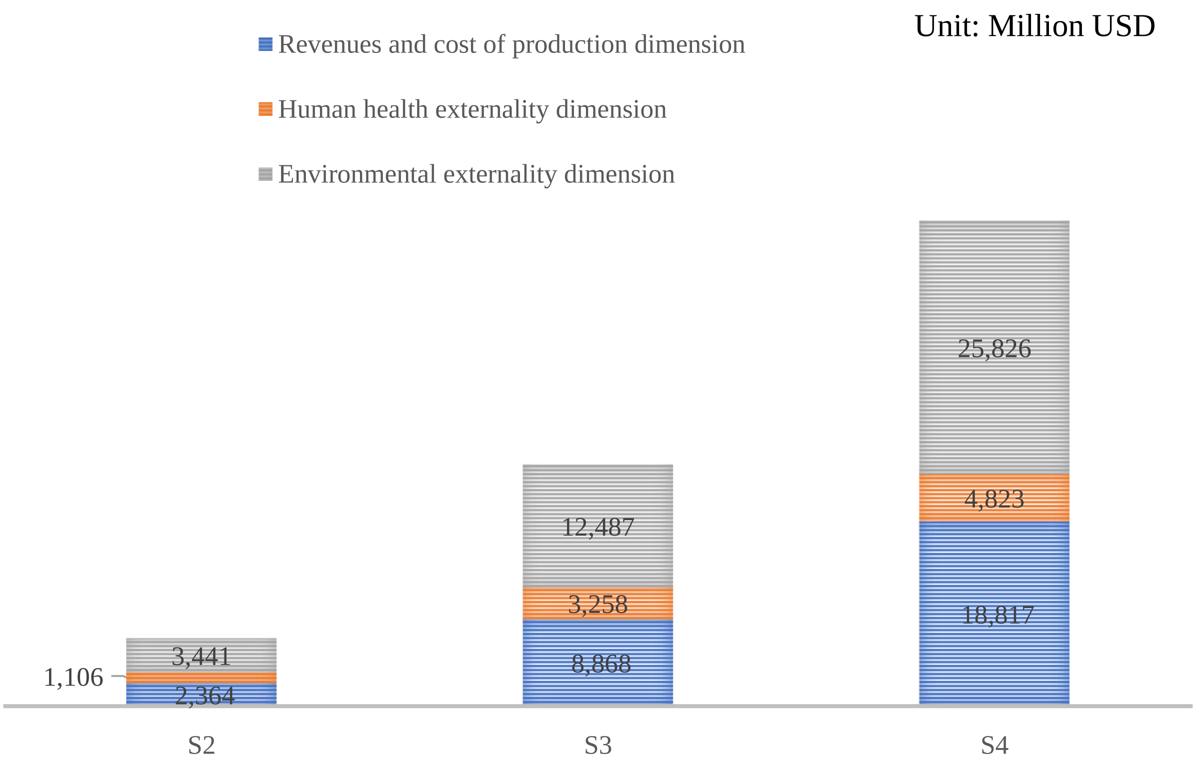
The total values gained and lost from a switch to conventional to sustainable rice practice from three options is presented in figures 5.3 to 5.5.

In the *rice only* condition, the fourth scenario projects the highest net benefit overall compared to BAU with the accumulated net benefit from 2022 to 2050 assessed to be

$49,460 million US dollars. The potential positive value is comprised of environmental gains which include GHG emissions reduction (1,853.43 million tons of CO_2eq) and soil organic carbon sequestration (2,427.34 million tons of CO_2eq), together projected to be worth $25,826 million US in net present value. Another value gained over time is the projected increase in rice production (of 130.15 million tons of rice). This production increase is projected to generate a positive value of $18,817 million US dollars. This is mainly due to the benefits gained from double rice production using sustainable rice practices in the irrigated areas of the Northeast region.

The net gains projected in Scenario 4 for the conditions involving *rice followed by other crops* provided similar pattern to *rice only*, with total value of $39,339 million and $36,969 million, for maize and sunn hemp respectively.

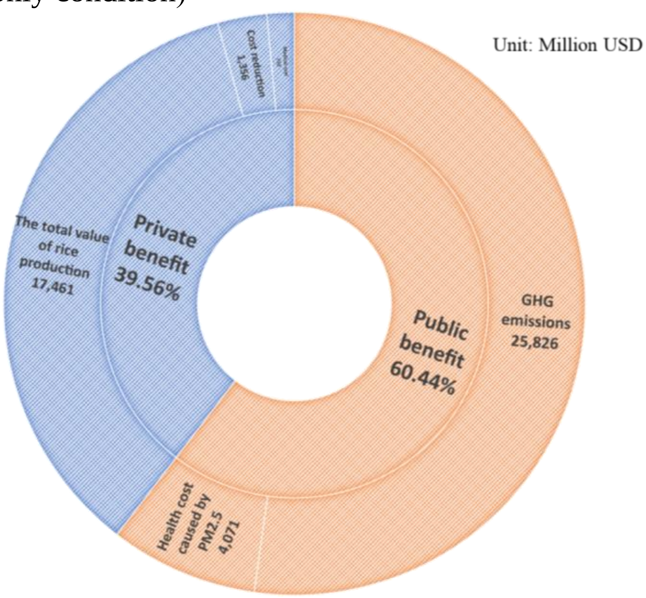
Figure 5.3 Overall benefit values of *rice only* condition in each scenario from 2022 to 2050 compared to BAU



Distributional analysis

The research team analyzed to whom these benefits accrued, to understand the share that was gained by farmers and the public. The accumulated value of *rice only* condition in the fourth scenario is presented by figure 5.4. This showed that about 60 percent of the benefits assessed to be gained fall back to the public sector, in particular in terms of the reduction in GHG emissions and health cost reduction from reducing PM2.5. About 40 percent of the benefits assessed are gained directly by farmers, in particular from an increase in profits from growing rice due to a significant increase in rice yield and reduction in cost of cultivation. Note that the private benefit is direct impact on rice cultivation and farmers, while the public benefit impacts all in society including farmers as a public good.

Figure 5.4 Illustration of the distribution of value gained by farmers and the public over time from the adoption of sustainable rice practice in the two regions according to the fourth scenario, 2022 to 2050 (rice only condition)



Figures 5.4 Sustainable rice practice not only mainly generates public benefit such as reducing GHG emissions and public health cost but also contributes benefits to farmers mainly through improvement of rice yield and reduction of cultivation cost resulting in an increase in profit from growing rice. An increase in profit of growing rice would be one of the main factors that could be a potential incentive to convince farmers to adopt sustainable rice practice.

5.2 The scenario analysis by regions

The nature, infrastructure, and management conditions in the Central and Northeast region are quite different. The central region has high humidity and hot temperatures with 10 years average temperature of 21.34 to 36.72 degrees and precipitation of 1,530 mm per year. Meanwhile the northeast is drier and with more fluctuating temperatures, with 10 years average temperature of 19.25 to 37.11 degrees and precipitation of 1,326 mm per year. The irrigation in central region cover about 44 percent of all agricultural area in the central, meanwhile that in northeast region is only 11 percent of all agricultural area in the northeast. Moreover, the second rice crop is cultivated in about 59 percent of all rice areas in the central region, but it is about only 5 percent of all rice area in the northeast. Due the different rice varieties, weather, infrastructures, and managements, the average rice yield in central is much higher than that in northeast with 3.78 and 2.24 ton per hectare respectively. Thus, in this section, the net benefits from land use change in each scenario were separately presented for two regions. The difference of climate conditions, irrigation system, soil types, rice varieties, and cultivation managements were the main issue in these two regions that provided the different production, cost, agricultural input use, as well as impacts from rice cultivation. The main results mainly focus on *rice only* condition. The monetized values of seven factors, related to human health, environment, and economics, as well as water consumption were explained together and illustrated to present trade-off analysis when sustainable rice practice is promoted.

Central region

In the Central region, about 50 percent of rice fields are supplied with irrigation systems, allowing double rice cropping in one year. In the *rice only* condition, health cost reduction from avoided emissions of PM2.5 and the environmental benefits of soil carbon sequestration are the significant benefits gained from switching to sustainable rice practice as presented by figures 5.5 and 5.6. However, total gray water consumption and its efficiency, water consumption per ton of rice production, were slightly lower than BAU situation. On the other hand, expansion of sustainable rice practice area results in reduction of blue water consumption when compared to conventional rice practice. In addition, the efficiency of blue water use in sustainable rice practice is also better than that of conventional counterpart.

Figure 5.5 Trade-offs for *rice only* condition in Central region in each scenario from 2021 -2050 relative to BAU

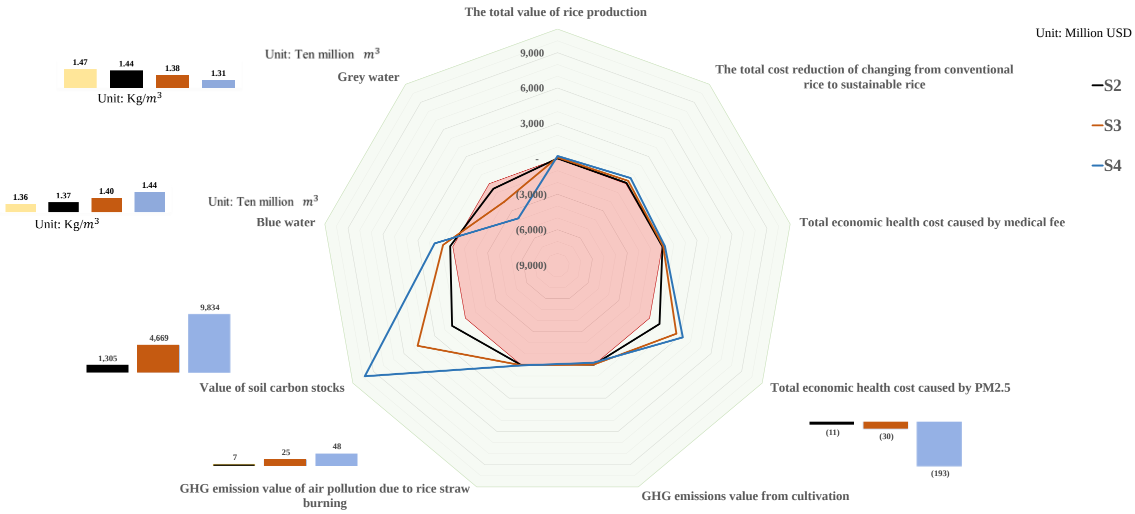
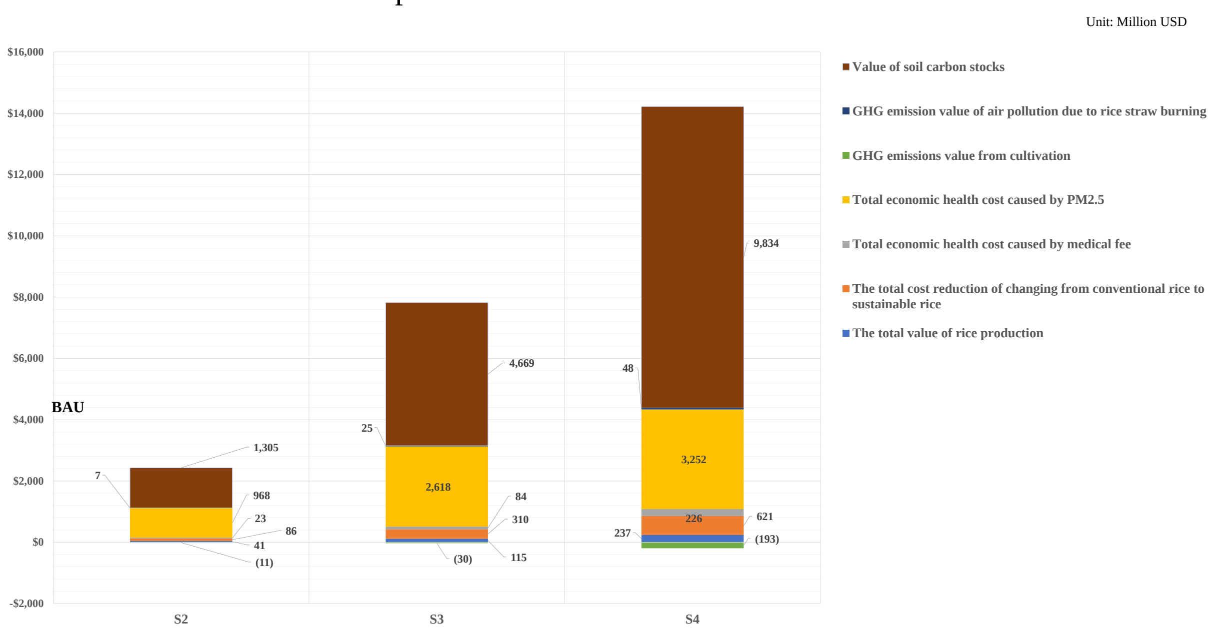


Figure 5.6 Scenario analysis based on *rice only* condition in more detail in Central region in each scenario from 2022 -2050 compared to BAU



For *Rice followed by sunn hemp* condition in the Central region, the tradeoff is clearly visible in this condition. Due to switching from off-season rice to sunn hemp in the dry season, the rice production is reduced significantly. In this condition, the expansion of sustainable rice practice area will result in reduction of rice production, which will impact income of farmers.

Northeast region

In the Northeast region, the results of expansion of sustainable rice practice are different from Central region in some measures. For the *rice only* condition, presented in figures 5.7 and 5.8, sustainable rice practice expansion could generate huge net benefit on rice production and soil organic carbon sequestration. The rice production under the expansion of sustainable rice area such as in scenario 4 increases by almost 50 percent when compared to that of BAU.

This also results in high water demand for blue and gray water. However, when we consider the efficiency of water use, which is more meaningful than the total water consumption, for both gray and blue water, expansion of sustainable rice practice generates better water use efficiency for both blue and gray water than those of BAU. This means that by the same amount of water use, blue and gray water, sustainable rice practice provides more rice production than conventional counterpart.

Figure 5.7 The shapes of trade-off chart with *rice only* condition in the Northeast region in each scenario from 2022 - 2050 compared to BAU

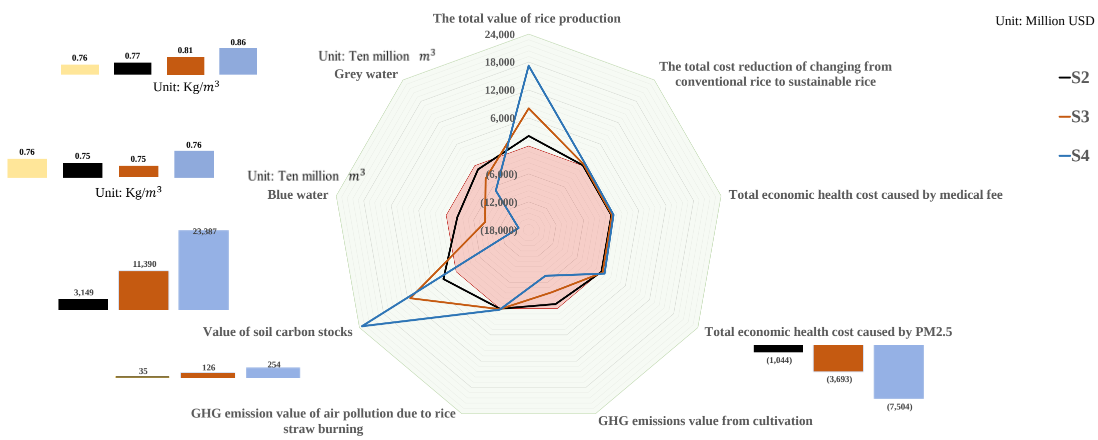
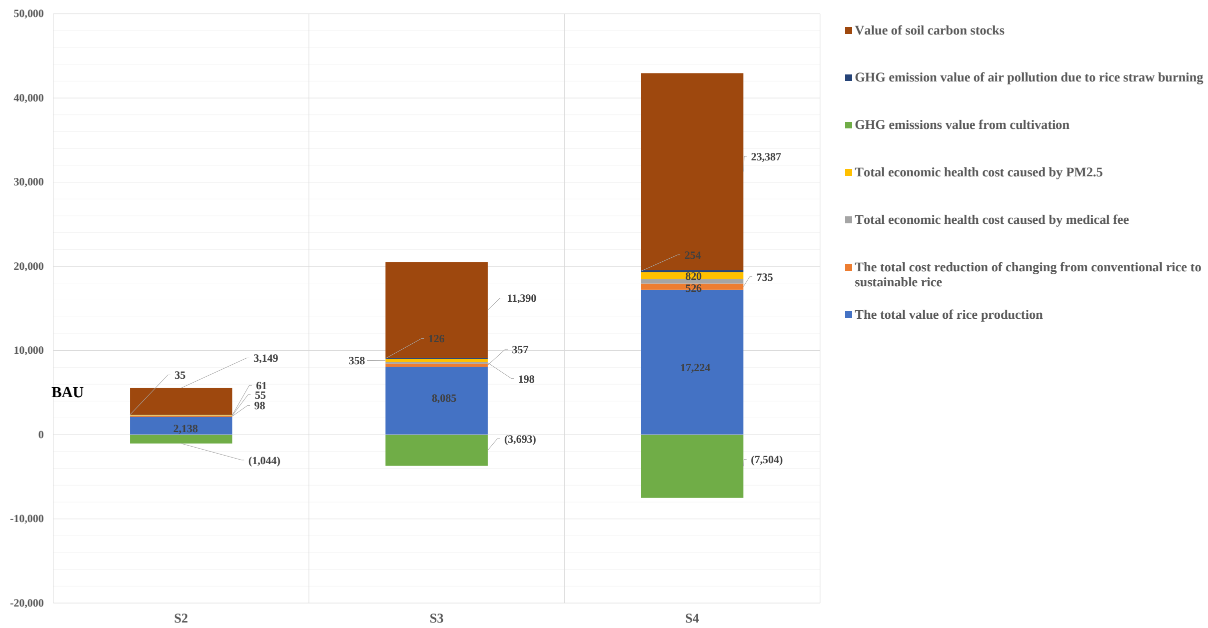


Figure 5.8 The scenario analysis based on values with *rice only* condition in more details in Northeast region in each scenario from 2022 -2050 compared to BAU

Unit: Million USD



6. Conclusions, Key messages, and Policy discussion

6.1 Conclusions

This study investigates the direct and indirect effects of switching from conventional to sustainable rice practice in the Central and Northeast regions of Thailand. The rice area of these two regions currently covers more than 80 percent of rice cultivation area in Thailand. The TEEBAgriFood framework is applied to observe the changes in produced, natural, human, and social capitals based on four land use scenarios, which vary by the different proportion of conventional and sustainable rice area. The timeframe for scenario analysis is 28 years, starting in 2022 and ending in 2050.

The overall result shows the effects of transferring from conventional to sustainable rice practice along 28 years in the Central and Northeast regions. The greater the area of sustainable rice practice generates the greater benefits overall. A transformation to sustainable rice practice would provide significant improvement in the net benefit resulting from improvement of private benefits to farmers, which include an increase in rice yield, cultivation cost reduction, and health cost reduction from pesticides. These private benefits from 2022-2050 gained by farmers are about 19 billion USD dollars. In addition, public benefits or positive externalities are visible from our analysis. The gains of public benefits cover the overall GHG reduction mainly from soil carbon sequestrations and the cessation of rice residue burning. The benefits of reduction of GHG value about 25 billion USD dollars cumulatively from 2022 to 2050. Furthermore, the public health cost reduction from less air pollution from rice residue burning due to expansion of sustainable rice area is significant. This benefit generated from sustainable rice area from 2022-2050 is about 4 billion USD dollars. In addition, water use efficiency especially in irrigated area is improved by an increase in sustainable rice practice area. From overall perspective, the sustainable rice practice clearly provides better benefits directly to farmers and public than conventional counterpart with no significant tradeoff.

When exploring the cultivation process options of sustainable rice practice in detail, this study found interesting evidence. If farmers grow rice twice a year in irrigated areas, the benefit gained from switching from conventional production to sustainable practice is tremendous due to significant improvement of yield under this practice. However, the demand for blue and gray water is also significantly high. On the other hand, if rice is grown only one time a year in the irrigated area and followed by soil improvement crops such as sunn-hemp during dry season, the demand for blue and gray water would be significantly reduced by about 30 to 40 percent with enhancing more soil fertility in the long run. However, this comes with a cost of rice production reduction by about 40 percent as it is grown only one a year especially in the Central region. This also implies that farmers' income from rice will be decreased too.

When our analysis was broken down to region level, the Northeast region provided a huge change in value of rice production due to dramatically increase in yield by over 60 percent from adopting sustainable rice practice. On the one hand, the yield improvement in the Central region from adopting sustainable rice practice is marginal compared to the Northeast region. This suggests that private benefit, especially an increase in income from adopting sustainable rice practice, would be more salient to Northeast farmers than those from Central region. However, when considering to the public benefits, even though expanding sustainable rice practice area in both regions yields better public benefits for GHG emission reduction, public health cost reduction, and water use efficiency, Central region seems to provide higher benefit than the Northeast region in this dimension. Due to more than 50 percent of rice areas of our study site in the Central region being in irrigated area, the alternate wetting and drying practice could be employed resulting in significant decrease in GHG emission during cultivation. In addition to the reduction of GHG during cultivation, another significant gain from expanding sustainable rice in the Central region is public health cost reduction from PM2.5. This is because the current situation of rice field burning in the Central region is more serious than that in the Northeast region especially in the irrigated area where rice is grown twice a year. In this area, farmers usually burn rice field to prepare their land for the next crop resulting high concentration of rice field burning in relatively short period when compared to the Northeast region. Expansion of sustainable rice area, which does not allow rice filed burning, would decrease air pollution especially PM2.5 resulting in greater benefit of public health cost reduction in Central region, which is about 3 billion USD dollars, than that of the Northeast region, which is about 800 million USD dollars.

The other measurements that are not included in our scenario analysis due to no appropriate financial proxy available or could not be quantitatively measured are insect biodiversity, trees on farms, and social capital. The result showed that the insect biodiversity index between these two practices within each region is not statistically significantly different, but the biodiversity index of the Northeast region seems to be better than that of the Central region. The sustainable rice practice is related to more quantity of trees and more diversification of trees on farms than conventional rice practice in both regions. However, the results of trees on farm need to be interpreted carefully due to limitation of this study to clarify the causation. For the social capital, communities and farmers adopting sustainable rice practice seem to have better social capital than conventional counterpart at least in term of trust, gender equality, prosocial behavior, and happiness especially meaning of lives.

All in all, public and private benefits generated from an increase in sustainable rice areas are positive in both two regions**.** Our model predictions and scenario analysis clearly shed light that the expansion of sustainable rice area in both regions would bring higher net benefit to rice farmers and public. The clear visible private benefits to farmers are higher profit from growing rice due to better yield and lower cost of cultivation, and less risk of being sick from pesticide poisoning. Public receives better benefits from expansion of sustainable rice practice in forms of GHG emission reduction, better health condition due to less air pollution, higher efficiency of water use and water availability. However, we need to be careful to keep in mind that the decision to adopt the sustainable rice practice mainly depends on farmers. The information of benefit gains especially from yield improvement and cost reduction alone may not be enough to convince farmers to significantly switch from conventional rice practice to sustainable rice practice as the majority of Thai rice farmers economic condition is uncertain. To influence them to change from conventional practice to sustainable rice practice, policymakers therefore need to consider forms of interventions that could incentivize farmers to try the sustainable rice practice, and cope with any risks that may occur during transition period until the benefits from yield improvement and cost reduction from sustainable rice practice are clearly visible by farmers.

6.2 Summary of Key messages

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- bein. 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. A direct switch from conventional to sustainable rice under the transformative scenario 4 provided the highest net benefit compared to BAU, assessed to be $49,460 million US dollars cumulatively from 2022 to 2050. This value accrues to both the public and to farmers. Farmers are projected to generate more profit per ha from sustainable rice practice in both regions, compared with conventional practice, particularly in the Northeastern region, driven by an increase in rice yield, reductions in expenditure on chemical fertilizers and pesticides as well as reduced labour costs. Net GHG emissions are projected to be lower under sustainable rice practices compared to conventional, resulting from higher soil organic carbon and from the elimination of stubble burning which would more than offset higher CH4 and N2O emissions from cultivation practices.

5. Rice yields are affected by cultivation practices, seeds, and environmental conditions. The findings from this study suggest that sustainable rice practice would generate significant yield improvement by over 60 percent compared to conventional counterpart especially in the Northeast region. Combining with the cultivation cost reduction, the profit from growing rice earned by farmers would be significantly increased compared to conventional rice practice.

6. 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 sustainable 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. In addition, if the alternate wetting and drying technique (AWD) could be employed, the GHG emission during cultivation could be further reduced. Overall, sustainable rice practice generates lower overall GHG emissions per hectare than conventional rice practice.

7. Biodiversity is affected by cultivation practices. This study finds clear evidence of rice fields' biodiversity improvements especially insect varieties and structure of predators and pests from expansion of sustainable rice practice at landscape level. The findings underscore the potential benefits of sustainable rice practice for biodiversity and pest management, with implications for conservation and land use decisions.
8. Rice cultivation is the main source of water use in agricultural sector of Thailand. Expansion of sustainable rice practice leads to reduction of water use by 30 to 40 percent especially in the irrigated area. In addition, the expansion of sustainable rice area improves water use efficiency.
9. The impacts of conventional rice production have negative externalities on human health. The analysis found that policy pathways for sustainable rice expansion improve human health, through reduced exposure to pesticides and air pollution. These benefits gained would sum up to 19 billion USD dollars from 2022-2050.
10. Sustainable rice production generates other benefits to human well-being for society, food, and culture.

6.3 Policy discussion and recommendations

Rice production is the main agricultural activity in Thailand as rice fields cover more than 50 percent of country agricultural area. Furthermore, about 20 percent of the nation's households, or 4.30 from 21.58 million households, are rice farmers. The cumulative impacts of production practices at farm level are therefore significant not only at regional level but also at national and international levels.

Under business as usual (BAU) where there is no intervention to promote transformation from conventional rice practice to sustainable rice practice, over the period to 2050, the models developed in this study predict that the rice production under conventional rice practice would maintain at the current level. However, the current conventional rice practice would induce more GHG emission, inefficiency of water use, and impose significant risk to human health. By comparing the values of these losses to ecosystem services and human health with the equivalent values from the scenarios that promote sustainable rice production, a strong economic case can be made to support this shift to sustainable farming systems.

1. The sustainable rice practice generates positive externalities through public health improvement and environmental improvement. In addition, the sustainable rice practice would be able to deliver private economic benefit to farmers through rice yield improvement and cultivation cost reduction resulting in increased profits from growing rice. However, an increase in profit could not be realized in the early period of conversion. On the other hand, the costs of conversion such as soil fertility evaluation, land leveling, and nutrient management are immediate costs faced by farmers. Therefore, convincing farmers to adopt sustainable rice practice without any supports especially during transition period may not be enough to significantly increase adoption rate. Government should step in to ensure farmers that any costs and risks posed on farmers would be managed and mitigated until the private benefits from adopting sustainable rice practice could be realized by farmers, which would take at least 2 to 3 years.
2. One of the main tools in agriculture to support farmers is subsidy. The main subsidy policies in agriculture currently focus on mitigating financial hardship of farmers. However, it does not encourage farmers to adopt sustainable agricultural practice like sustainable rice practice because this form of subsidy somewhat sends a signal to farmers that government will always step in to help them whatever practices they apply for rice cultivation. We propose that subsidy should be reoriented with condition on adopting sustainable agricultural practice such as sustainable rice practice.
3. Conversion to sustainable rice practice requires some management and access to necessary inputs such as soil nutrient evaluation, land leveling equipment, and fertilizers suitable for soil nutrient. Many farmers may not be able to efficiently access these techniques and inputs. Even though they would like to try the sustainable rice practice, without supports for these it is unlikely that the adoption of sustainable rice practice would be successful. We propose that the government should set up efficient systems that provide these kinds of supports to farmers.
4. The sustainable rice practice could provide high potential net benefit, which would be up to 50 billion USD dollars, from dimension of environmental and human health externality. Most of these impacts are the public benefits that farmers have generated but could not receive the direct financial benefit, which is the high potential motivation to adopt friendly environmental practices.

In the fourth scenario, four billion USD dollars of the benefit of health impact from reducing PM2.5 is tremendously high because of stubble burning prohibition in the sustainable rice practice. Rice fields in irrigated area, growing at least two crops of rice a year, are the main area of rice field burning because farmers want to speed up the process of preparing the rice field for the next crop. Waiting for rice straw and stubble to naturally decompose is not the option for farmers. We propose that the supports of technologies and innovations to handle with stubble decomposing would help farmers to reduce time and provide more practical ways to adopt no stubble burning.

5. The sustainable rice practice could reduce high GHG emission from soil carbon sequestration. Moreover, in the irrigation area, the alternate wet and dry technique (AWD) could be employed. From our results, this technique significantly reduces GHG emission, mainly from methane, from rice cultivation. However, these public benefits are invisible to farmers. The promotion of economic or market mechanism that could transfer this invisible benefit to financial benefit for farmers could play an important role. The voluntary carbon market could be one of the solutions, but for rice production, the possibility to achieve financial feasibility for capture carbon credit is currently low due to the high cost of validation process. Thus, the low transaction cost and internationally acceptable method to capture carbon credit are highly necessary.
6. Widely transforming from conventional rice practice to sustainable rice practice would require significant supports from the government especially during the early period of conversion. If the budget is limited, our study suggests that starting transformation from conventional rice practice to sustainable rice practice in the Northeast region would be more cost effective than in the Central region as the net benefit gained from both private benefit and public benefit of transformation are clearly visible. In addition, according to Mungkung et al. (2022) the current rice cultivation practice in the Northeast region is significantly closer to the sustainable rice practice than that in the Central region, suggesting that the transformation in the Northeast region would be practically more possible and would require lower cost than that in the Central region.

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