Integrating the Value of Ecosystems and Biodiversity in Rice Systems in Thailand

An analysis of alternative rice cultivation methods in northeast Thailand

Full findings Report, review copy

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production areas

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Introduction

Since 2005, the government has promoted Thailand as the "Kitchen of the world", supporting Thai agriculture to meet export demand. In 2017, Thailand ranked 12th worldwide for agricultural outputs overall, and has significant global food commodity exports of rice, sugar, cassava, chicken, seafood, and pineapple (BOI, 2020). The rice sector plays an important role in the social, economic, and environmental development of Thailand. The Thai government has provided strong support to the rice sector by distributing a substantial budget to promote this sector, such as the project of rice market system, organic rice promotion, rice price subsidy, and rice input subsidy, covering almost 10 billion baht ($0.33 billion) annually (Ministry of Agriculture and Cooperatives, 2019). Rice production is integral to Thailand's culture, agricultural landscapes and rural livelihoods, particularly in the area of focus in the Northeast. 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 are over 50 percent of total agricultural area in Thailand, about 9.59 million hectares in 2019 (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. Until 2012, Thailand was the leading rice exporter in the world, and now is second only to India (FAOSTAT, 2020). Exports of Thai rice are traded throughout the world, with Benin being the largest importer of Thai rice in 2018 and 2019 by volume (Thai Rice Exporters Association, 2019).

There is a rich literature of academic and policy studies which have investigated the impacts of different aspects of rice production practices in different countries. The majority of analyses have tended to focus on economic aspects of trade, national income, rural livelihoods, and related agronomic aspects to achieve production efficiency and yield improvements and investigate innovations in machinery and practice. The focus of the TEEBAgriFood Initiative, of which this study forms part, is not only on food production and economic indicators alone, but also extends to the dimensions of environment, society, and human well-being.

The impacts of rice production on environment and ecosystem services have also been well investigated. There have been many studies assessing, for example, the generation of green-house gas (GHG) emissions and energy use in different rice cultivation practices (e.g. Hokazono et al. 2015; Soni et al. 2013); the impacts of different rice production practices on biodiversity (e.g. Dalzochio et at. 2016; Bacenetti et al. 2016); economic and ecological efficiency beyond the farmgate of comparative rice production practices (e.g. Adhikari 2011; Arayaphong 2012; Masuda 2019).

Settele et al (2018) outline the findings from an extensive literature on provisioning, regulating, and cultural ecosystem services in irrigated rice landscapes, developed through the Legato project which was aimed at developing and testing ecological engineering principles for the stabilisation and improvement of agricultural production under future climate and land use change. Garbach et al. (2014) reviewed the results of 155 studies, comprising 21 on conservation agriculture, 32 on integrated farming systems, 20 on integrated pest management, 20 on organic agriculture, 22 on the System of Rice Intensification, and 40 on holistic heritage agricultural systems to assess the extent to which different systems enhanced or diminished ecosystem services and yields. The impact of different rice cultivation practices on human health, consumer awareness, and society have also been addressed by various studies (eg Hossain et al. 2007; Ibitoye et al. 2014; Jaijit et al. 2018).

Most studies, however, have concerned specific elements or aspects of rice production systems, and do not cover entire value chain of rice production system. The present analysis will build on this rich body of scientific and analytical work in aiming to present a broad comprehensive analysis of the rice sector, that can help us to understand and incorporate the relationships between agriculture and food, the environment and human well-being. Moreover, there has not been to date a systematic study, which compares the economic benefits and costs seeking to incorporate all positive and negative externalities between organic and conventional rice cultivation practices in Thailand.

Hence, this study aims to present a comparative investigation of rice production systems in Thailand addressing natural, produced, human and social capital impacts along the whole value chain of rice production by applying the TEEBAgriFood Evaluation Framework.

TEEB refers to the Economics of Ecosystems and Biodiversity. The TEEBAgriFood initiative was developed in response to the need for a transformative change in food systems in order to meet the internationally agreed Sustainable Development Goals. TEEBAgriFood is a global initiative of the UN Environment Programme that seeks to achieve positive human livelihood outcomes and biodiversity improvements through the application of the TEEB Evaluation Framework developed through a collaboration of scientists from many different countries and disciplines. The TEEBAgriFood Evaluation Framework and 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 (TEEB, 2018). The components of this framework are illustrated in figure A below, which highlights the dependencies and impacts of the agri-food system upon natural, produced, social and human capitals. 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 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 based on scientific research

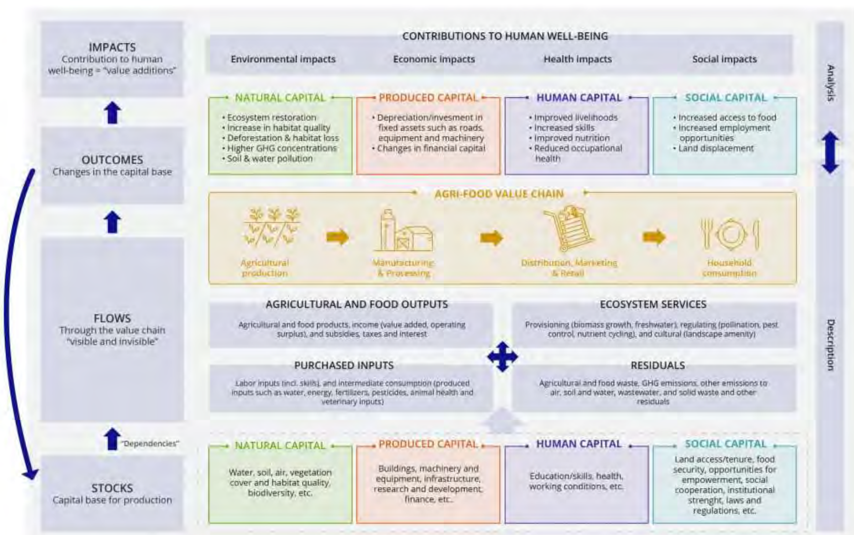


Figure A: TEEBAgriFood Evaluation Framework: capturing 'invisible' costs of agrifood systems in conventional economic analysis

The TEEBAgriFood Evaluation Framework is being applied extensively (TEEB, 2020). In 2017, an international consortium including FAO, IRRI, TruCost, Bioversity International and UNEP applied the TEEBAgriFood approach to the rice farming sector in Senegal, US, Cambodia, Costa Rica and Philippines which identified the types of farm management practices or systems that reduce trade-offs and allow for maximization of benefits for society, environment and wellbeing of the farmer[1].

Thailand currently joins ten other countries (Brazil, China, Colombia, India, Indonesia, Kenya, Malaysia, Mexico and Tanzania) in piloting the 'TEEB for Agriculture & Food' (TEEBAgriFood) approach to 'Measuring what Matters' in agriculture and food systems.

Based on the TEEBAgriFood Evaluation Framework – Guidelines for Implementation[2], there are main four steps of the study framework as shown in figure B.

[1] http://teebweb.org/agrifood/home/rice/
[2] https://futureoffood.org/wp-content/uploads/2020/09/GA_TEEBAgriFood_Guidance.pdf

Figure B - Phases and steps in applying the Framework

PHASE 1: FRAME	PHASE 2: DESCRIBE & SCOPE	PHASE 3: MEASURE & VALUE	PHASE 4: TAKE ACTION
Step 1: Outline your interest	Step 6: Describe the system	Step 16: Select an analytical approach & method	Step 21: Identify who is affected
Step 2: Determine the issue of interest	Step 7: Describe the agri-food value chain	Step 17: Select appropriate variables & indicators	Step 22: Apply & act on your results
Step 3: Clarify the purpose	Step 8: Describe the activities of interest	Step 18: Collect data & measure	Step 23: Communicate your results
Step 4: Identify stakeholders & form an advisory committee	Step 9: Describe the capital stocks	Step 19: Apply value to your measurement	
Step 5: Outline an action plan for your results	Step 10: Describe the flows	Step 20: Validate your study & test key assumptions	
	Step 11: Describe the outcomes		
	Step 12: Describe the impacts		
	Step 13: Assess materiality		
	Step 14: Select impacts for assessment		
	Step 15: Identify opportunities for change		

Source: Eigenraam, et. al., (2020)

The first step, the identification of study area and purpose, was developed through the project Inception Workshop, with contributions from multiple stakeholders (TEEB, 2018) and refined by the project Steering Committee, chaired by the Office of Natural Resources and Environment Policy and Planning (ONEP), Ministry of Environment and Natural Resources (MoNRE). Committee members were from Department of National Parks, Wildlife and Plant Conservation, Department of Environmental Quality Promotion (MoNRE), Department of Agriculture, Department of Agriculture Extension, Rice Department, National Bureau of Agricultural Commodity and Food Standards, Royal Forest Department, Department of Fisheries, and the Department of Livestock Development, from the Ministry of Agriculture and Cooperatives (MOAC), and the National Economic and Social Development Board, (NESDC). Thus, it was agreed that the study will examine trade-offs in ecosystem services between conventional and organic production practices, including rice output, incomes, and externalities such as water contamination. The main agreed components of the TEEBAgriFood study are included in the TOR annexed to this report (Annex 1).

The next steps were to research information concerning study sites and ecosystem functions and define the scope of study including a mapping and delineation of the areas and systems to be analysed, a mapping of the value chain, identification of relevant actors and system relationships as well as proposing the temporal and spatial scales of assessment and scenario development. The results of this work were presented in the TEEBAgriFood Scoping Report, which was presented, along with a detailed Methodologies Report, to the key project stakeholders at a project Steering Committee meeting held in Bangkok in September 2020. Based on the agreed study scope and methodological approach, the report herein presents a follow up report detailing the measurement and valuation of the dependencies and impacts of rice production systems on ecosystem services and biodiversity.

This report along with, a summary of the results of the assessment will be presented to stakeholders for discussion, validation, and further development in a further Steering Committee Meeting and a national workshop with other key stakeholders in the first half of 2021. Following this process of discussion and validation, the final step in the process will be for the results of the analysis to be mainstreamed into public and private decision-making processes and enable key actors to recognize the values of biodiversity and ecosystem services as a cornerstone of agriculture and food system

Part 1 Delineation and mapping of the current rice production areas

This section of the report sets out a description of the focus of the analysis, which is the rice sector in Thailand and, in particular rainfed lowland rice production under organic cultivation system in the Northeast of the country. This introduces the current land use, the situation of rice production, and the significance of Thai rice production in these areas. Moreover, the report provides information concerning the study sites, located in the Northeast region. Finally, it outlines the rice value chain, and identifies the linkages of rice production systems with biodiversity and ecosystems services.

1. Rice farmers and rice production

Thailand's rice agro-ecosystems provide livelihoods for approximately 4.4 million farming households or approximately 20 million people (approximately 28 percent of the Thai population) (National Statistical Office, 2019). Rice is the main staple food of Thai households, with many families consuming rice-based meals 3 times a day. Rice is cultivated on almost half (46 percent) of Thailand's agricultural land (OAE, 2019).

Most rice farmers are identified as small-scale farmers, holding on average of 2.08 hectares of land per household (OAE, 2018). Over a fifth of all rice farming households cultivate on less than 1 ha of land. There is no simple correlation between landholding and a standard definition of smallholders. Soil fertility varies greatly, such that the size of a smallholding in one region may be smaller than what is considered a viable smallholding in another region. The OAE provide data for the number of rice farming households with less than 1.3 ha (<10 rai), which in the 2019/2020 season consisted of 1.93 million households or 43.59% of all rice farming households. Approximately 3.54 million rice farming households, or 80% of all rice farming households in Thailand in 2019 held less than 3.2 ha (<20 rai)[3].

The average age of a Thai farmer is 58 years old. Both men and women are engaged in all tasks within rice farming, cattle rearing, and the gathering of wild foods, although there are a few specific roles for men and women relating to spiritual ceremonies of blessing the land, water, young rice shoots, and the harvest.

[3] http://www.oae.go.th/assets/portals/1/fileups/prcaidata/files/holdland%2062(3).pdf

Most rice farmers rely on income from other sectors (Attavanich, W., S., et al., 2020), and have been affected by the lack of alternative seasonal employment during the Covid pandemic.

The average annual income from rice farming is 27,812.5 baht per hectare (about $927) per year. The average annual household debt of Thai farmers was 200,689 baht ($6,690) in 2015 (National Statistical Office). Thailand produced approximately 28.35 million tonnes of paddy rice[4] in 2019 (FAOstat, 2019). The country's average yield of paddy rice per hectare in 2019 was 2.91 ton (FAOstat, 2019).

When considering the milled equivalent of the total rice production, the amount produced in Thailand in 2019 was 18.914 million tonnes. About one third of this total was traded internationally in 2019 (FAOstat), or 6.848 million tonnes in export quantity.

1.1 Rice agro-ecosystems in Thailand

Rice agro-ecosystems also provide habitats for diverse flora and fauna species which vary with different cultivation processes (Edirisinghe and Bambaradeniya 2006; Bambaradeniya et al. 2004). The agronomic practice for managing monoculture rice crop, from seedling to harvesting, and can quickly change rice field into various habitat states based on water regime, drainage, temperature, soil type, topography, and locations. Therefore, in a short-term, within a single crop rotation, the ecosystem of rice field encompasses a diversity of habitat states that are ephemeral, in that they provide a variety of niches for diverse life forms (Bambaradeniya et al. 2004). Rice bunds are normally built-up separating paddy fields to manage water flow, these can provide semi-wild habitats amongst the agricultural fields, often with flowering plants. It is not uncommon to see toddy palms within rice fields, and a wide variety of trees planted along the boundaries of the paddy fields, including banana plants, fruit trees, timber or shade trees.

Traditionally, paddy field management allow not only for harvest of rice grains, but also yield small catches of fish, rodents, amphibians, molluscs, crustaceans, and edible insects from the rice fields. Many are sources of food, medicine and some play an important role in biological control and facilitate agricultural production by recycling nutrients. Wild food plants are a critical component in the subsistence system of rice farmers in Northeast Thailand. According to a field study carried out in Northeast of Thailand (Cruz-Garcia and Price, 2011), anthropogenic areas

[4] Paddy rice or rice grain after threshing and winnowing, also known as rice in the husk or rough rice (FAOstat).

such as rice fields are very important sources of such wild food. More than two thirds of wild food species were reported as having diverse additional uses and more than half of them are also regarded as medicine. Women are locally recognized as knowledgeable about these plants.

High biodiversity in rice field are likely to promote trophic linkages which can alleviate pest damage and enrich soil fertility (Edirisinghe and Bambaradeniya 2006). Post-harvest, fields also provide pasture for cattle.

Other crops may be planted in the paddy fields during the rest of the year following the rice season, depending on climatic and soil conditions, including food crops such as beans, vegetables, onions or garlic. A small proportion of rice lands are re-used for a second or third crop of rice, where irrigation resources are sufficient, predominantly in the Central Plains and lower North region.

Biodiversity and the functioning of ecosystem services in the rice field are directly affected by rice farming practice and other changes to the agricultural landscape. The application of fertilizers and pesticides intended to ensure the highest yields may have multiple impacts including affecting the diversity of organisms causing loss of nutrients due to blooms of unicellular algae, rapid growth of ostracods and chironomid relating to cyanobacterial blooms, and proliferation of fresh water snails or mosquito larvae that can have harmful effect on human health and livelihoods (Roger, Heong, and Teng 1998). The number of studies stated that the organic practice provided richer biodiversity than that in conventional area. For example, a study in Korea found that rice fields cultivated with organic practices for eight years had a significantly higher number of species and individual birds compared with a field recently converted to organic or fields under conventional practices (Lee, 2011). The organic rice ecosystem increases species richness, species evenness and heterogeneity of insects from the non-organic area in Bantul, Indonesia (Ovawanda, E. A., Witjaksono, W., & Trisyono, Y. A., 2016). Higher levels of biodiversity in plants, invertebrates, birds and bats are found in the cereal organic farms than non-organic practice in lowland England (Fuller, R. J., et al., 2005). Moreover, the meta-data analysis of the issue in organic farms and biodiversity form 766 scientific studies presented that the organic practice areas are more advantage to biodiversity than that in conventional practice areas (Rahmann, G., 2011).

Different management practices of the rice paddy at different stages generate greenhouse gas (GHG) emissions from the field or carbon sequestration. A variety of land management practices, including increasing of fertilizer application and land practices such as paddy field flooding, full tillage, and burning of crop residues, contribute to GHG emissions in the agricultural sector along with different types of land use change. Flooded paddies are the biggest source (around 58%) of CH_4 emissions in Thailand. These are explored further in Part 4 of this report.

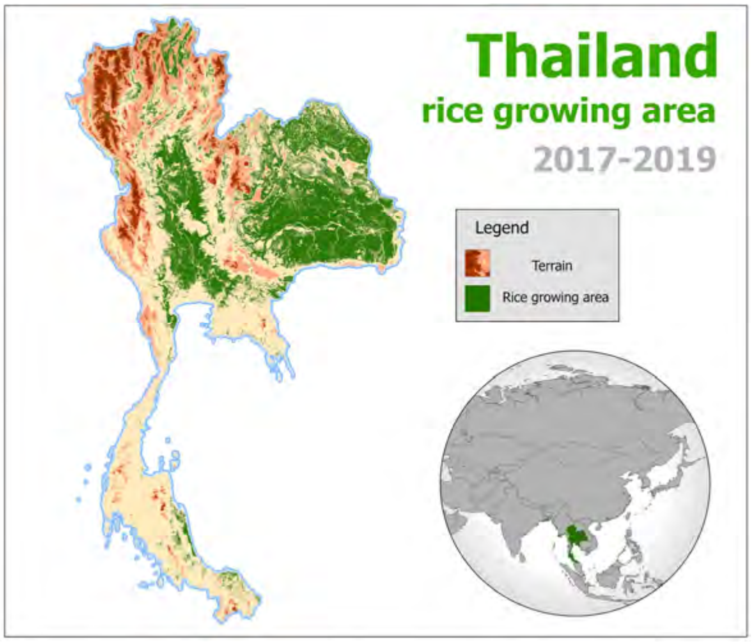
2. Land use for rice in the northeast of Thailand

As shown in figure 1.1, the main rice cultivation areas of Thailand are in the Northeast and Central & lower North regions. Rice systems in Thailand can be divided by ecological area into four categories including irrigated, rainfed lowland, deep-water, and upland cultivation (IRRE, 2019).

Irrigated areas are mostly located in the Central plains and lower North of Thailand. This area covers almost 23 percent of the area cultivated during the main season (*na pi*) spanning the monsoon rains. These areas mainly produce non-aromatic white rice.

The majority, or approximately 75 percent, of Thailand's rice fields are rainfed, and most of the rainfed lowland fields are located in the Northeast region of the country (Rice department, 2012). The aromatic and highly-valued Jasmine rice (*Hom Dok Mali*) is generally cultivated in rainfed lowland systems. Deep-water and upland (unflooded) fields are small part of rice cultivation system, and are also dependent on rainfall.

Figure 1.1 Main rice cultivation areas in Thailand



Source: Land Development Department (2020)

The Northeastern region is one of the most important agricultural areas of Thailand, and rice remains the predominant crop in the area, despite recent increases in other commodity crops over the last decade[5]. According to the Thai Office of Agricultural Economics (OAE), the total area of rice production nationwide is approximately 68,728,283 *rai* (10,996,525 hectares), of which approximately 60 percent is in the northeast region (41,747,009 rai or 6,679,521.44 hectares) (LDD, February 2019)[6]. Of the four main crops in the Northeast, rice production is the most widespread. In 2017, rice accounted for 64 percent of the main crop cultivation area (see

[5] Based on data from Land Development Department, the total agricultural area in the Northeast for cultivating four main crops, rice, cassava, sugarcane, and rubber tree, increased from 62.2 to 68.6 million rai (11 million hectares) from 2007 - 2017. The area under rice cultivation in this region declined however, during this period from 47.1 to 43.8 million rai, while other commodity crops increased, in particular rubber tree production.

[6] However, the official rice cultivation area data, provided by Office of Agricultural Economics, showed that the total area of rice production in 2018 was about 59,214,535 rai (9,474,325.6 hectare), of which approximately 62 percent is in the northeast region (36,589,600 rai or 5,854,336 hectare) (OAE, 2018). There is a big difference of data from land use map by LDD and statistical data by OAE. Nevertheless, both source of data still be needed in this study. The data of land use map by LDD will be utilized as visual land use change analysis, while the official data by OAE will be used as initial area in the scenario analysis.

figures 1.2 and 1.3 below), declining from 75 percent in 2007, while other commodity crops increased in area, in particular rubber trees.

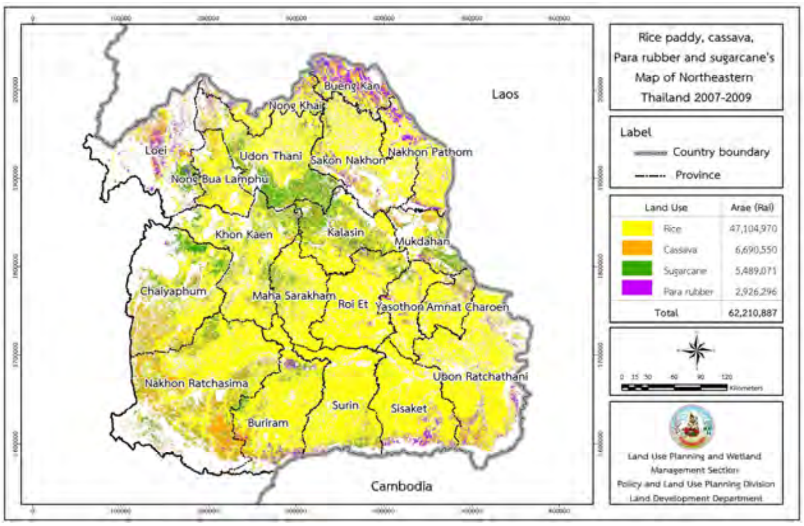
The majority of the organic rice production area is located in the northeastern provinces, particularly Khon Kaen, Amnat Charoen, Chaiyaphum, Buriram, and Roi Et. Elsewhere in the country, organic rice is also produced in the Northern part of Thailand in a relatively small area (including Chiang Rai, Phayao, and Chiang Mai provinces).

Table 1.1 Area of rice production in the 20 provinces of the Northeast of Thailand in 2019

Province	Total rice area* (1,000 Ha)	Organic rice area** (1,000 Ha)	Percentage of rice area that is certified organic %
Khon Kaen	400.70	37.05	9.25
Amnat Charoen	183.61	8.53	4.65
Chaiyaphum	259.88	9.74	3.75
Buriram	501.56	18.01	3.59
Roi Et	545.50	19.44	3.56
Nakhon Phanom	259.53	5.81	2.24
Bueng Kan	90.86	1.95	2.15
Nakhon Ratchasima	617.73	13.2	2.14
Maha Sarakham	313.53	5.39	1.72
Surin	546.35	7.11	1.30
Kalasin	241.46	2.73	1.13
Udon Thani	317.96	1.92	0.60
Yasothon	239.53	1.29	0.54
Nong Bua Lam Phu	104.80	0.47	0.45
Ubon Ratchathani	733.65	2.67	0.36
Si Sa Ket	534.45	1.47	0.28
Mukdahan	83.80	0.21	0.25
Sakon Nakhon	394.47	0.48	0.12
Nong Khai	112.65	0.06	0.05
Loei	77.37	0.03	0.04
Total Northeast	6,559.39	137.56	2.10

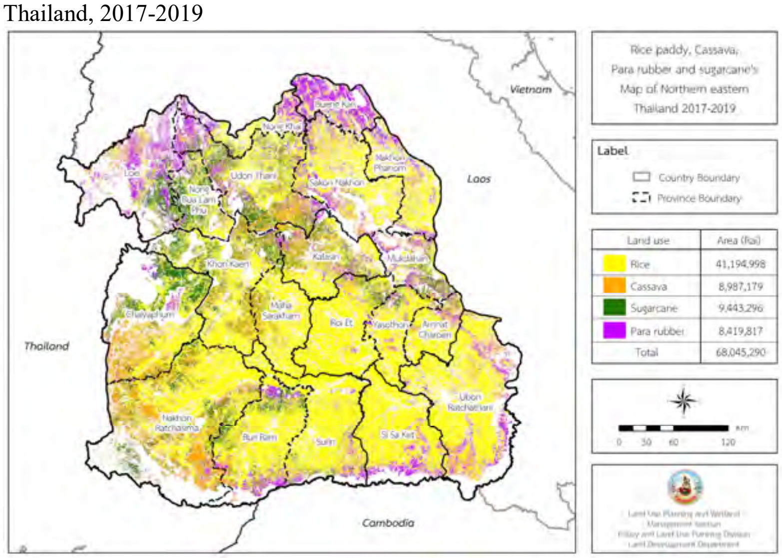
Source: * Land Development Department, ** Rice Department

Figures 1.2 Spatial distribution of 4 main crops, rice, cassava, rubber, sugarcane in Northeastern Thailand, 2007-2009



Source: Land Development Department (2020)

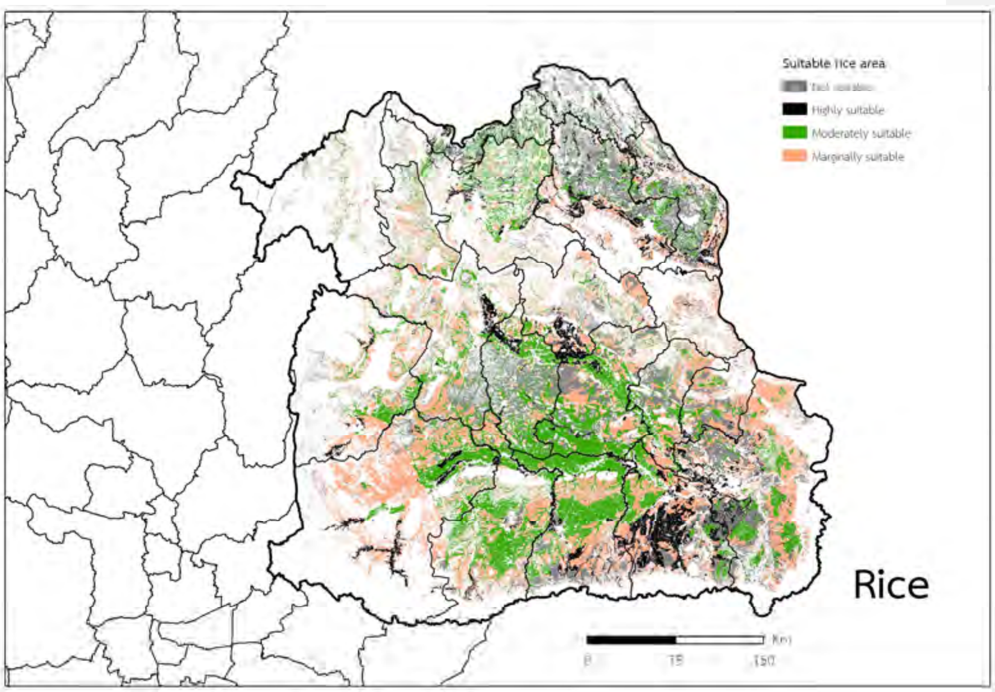
Figures 1.3 Spatial distribution of 4 main crops, rice, cassava, rubber, sugarcane in Northeastern Thailand, 2017-2019



Source: Land Development Department (2020)

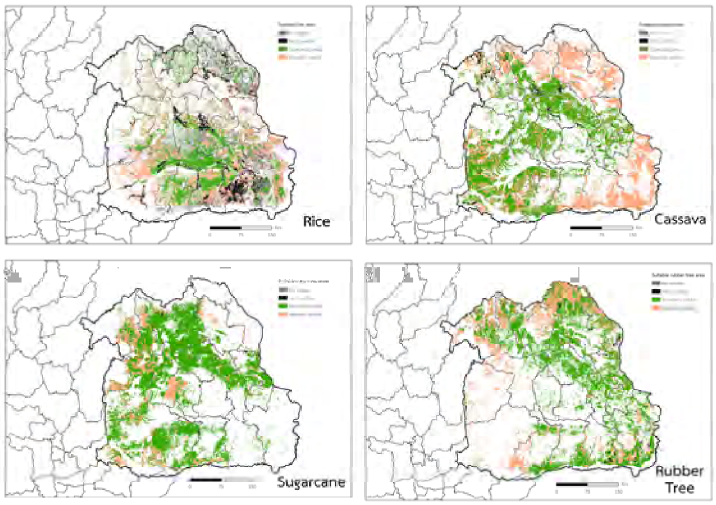
The Land Development Department has carried out an assessment of the areas that are suitable for rice cultivation, based on a suitability index further described below in Part 2.2. These areas are shown in figure 1.4, and land areas suitable for the four main crops in the Northeast of Thailand are shown in figure 1.5.

Figure 1.4 Map of Northeast of Thailand showing areas identified as suitable for rice by AgriMap project



Source: Land Development Department (2020)

Figure 1.5 Map of Northeast of Thailand showing areas identified as suitable for four crops

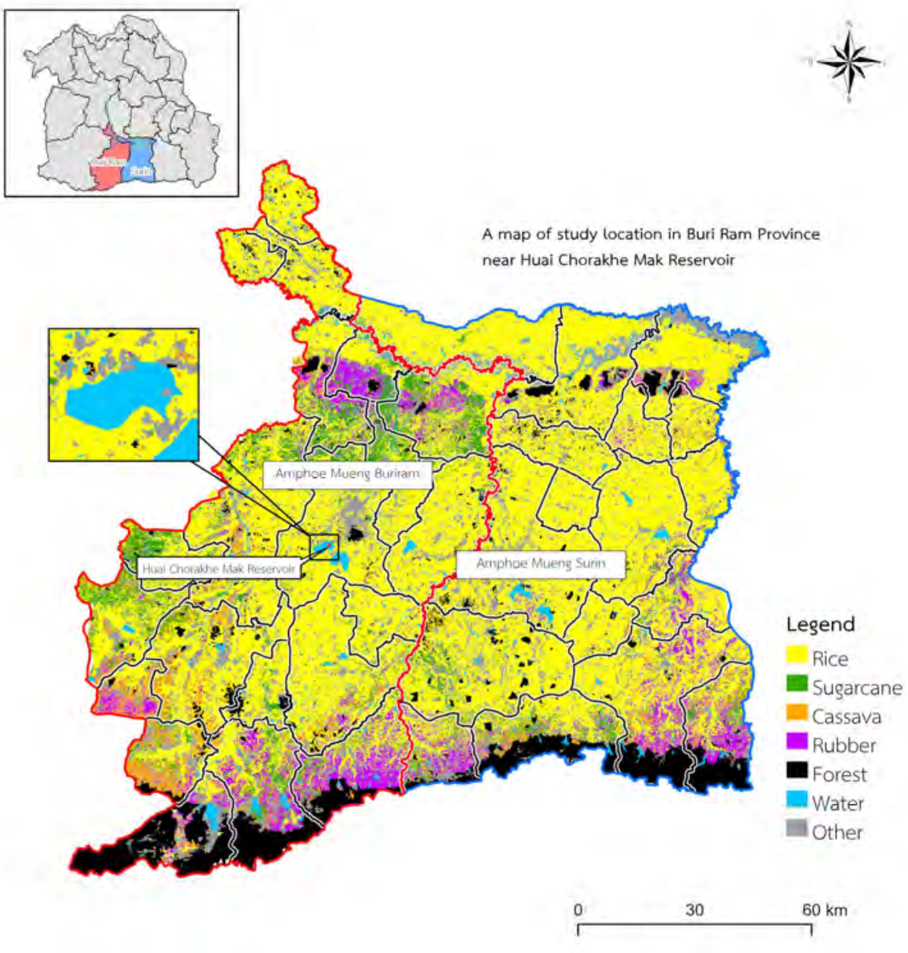


Source: Land development department (2020)

3. Focusing on the study sites: land use for rice in Buriram and Surin

The study is considered for the whole Northeast region in Thailand. However, for biodiversity data, field studies were conducted in Buriram and Surin provinces, located at the southern part of the Northeast region of Thailand. There are three main reasons that these two areas were selected for the study. Firstly, organic rice cultivation has been practiced for over 20 years in Surin province. There are at least seven producer groups of organic rice farmers in Surin province, covering an area of about 4,640 hectares[7]. Secondly, Buriram province is where the unique Huay Chorakhe Mak Reservoir and Sanambin Reservoirs are located (see Figure 1.6), which serve as the natural habitat for the Eastern Sarus Cranes (*Grus Antigone*). These reservoirs are surrounded by rice fields where the link between rice management practices and biodiversity conservation can be studied. The Eastern Sarus Cranes are known to use rice fields as feeding and nesting grounds. Here, organic rice farming is still in its infancy compared with Surin where such practices have been promoted and developed. Thirdly, since rice is the main crop in both provinces, it would be common to find areas where conventional and organic rice practices are applied in the same vicinity, allowing the scientific analysis team to control for some soil types, temperature, rainfall, public infrastructures, and culture, which would result in more precise measurement of benefits and costs (positive and negative externalities) between these two rice cultivation practices. The study sites are further described in the Methodologies report.

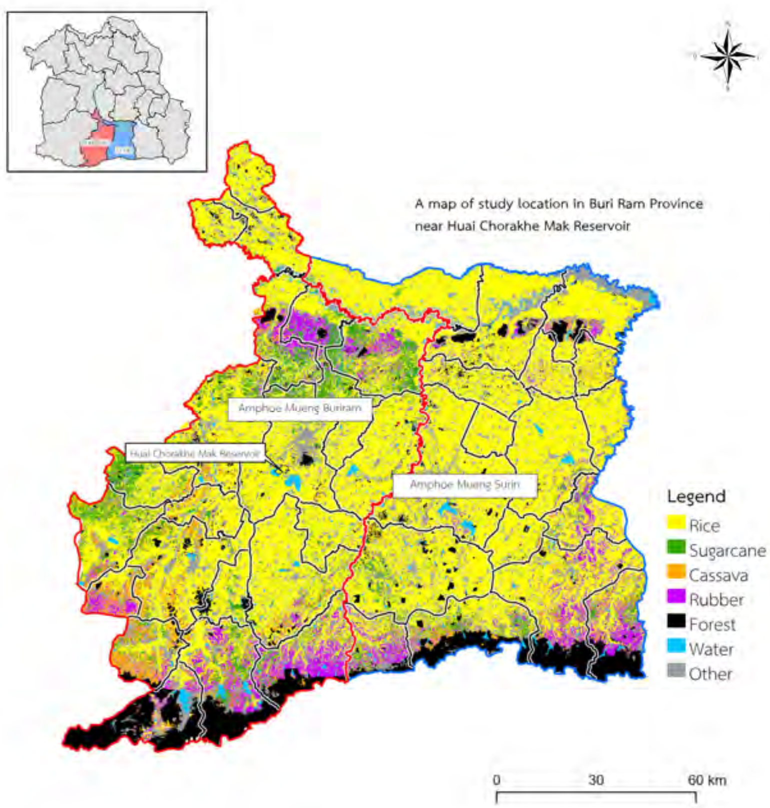
Figure 1.6 Map of study locations in Buriram Province near Huai Chorakhe Mak Reservoir



Source: Land Development Department (2020)

The section below delineates and maps the current rice production areas in these two provinces. Data provided by the Land Development Department, shows that rice is considered a highly suitable crop in the field study provinces of Buriram and Surin (figure 1.7). Around 76 percent of the total agricultural land area in these two provinces, or approximately 5.8 million rai (928,000 hectares) (OAE, 2019), is dedicated to rice production (see figure 1.7). The majority of rice farmland in Surin and Buriram is rainfed, that is without access to irrigation sources. Average rice yields per hectare in 2017 were below the national average at 2.244 tons/ha in Surin and 2.125 tons/ha in Buriram respectively.

Figure 1.7 Land use in Surin and Buriram, 2017



Source: Land Development Department

Less than one percent of this area is currently dedicated to organic rice (approximately 43,750 rai or 7,000 hectares). However, this area is significant in terms of national organic rice production, since Buriram and Surin represent approximately 13 percent of Thailand's total organic rice production area in 2017.

4. Production of Thai rice along the value chain

The main components that comprise the rice value chain, that is the whole range of goods and services necessary for rice to be grown at the farm, be processed, moved and provided to the final consumers, are summarized below and illustrated in figure 1.8. The inputs, flows and outputs of conventional and organic rice practices throughout the value chain in respect to natural capital, biodiversity and ecosystem services are identified and systematized in the Methodologies report.

Rice seed is supplied through informal, intermediary and formal channels (see Napasintuwong, 2018). The demand for rice seed, is about 1.117 million tons a year (Rice Seed Center, 2018). Informal channels are the most prevalent, and include farmers saving or exchanging rice seeds from their own fields. The supply of saved seeds and exchanged seeds was projected at 798,792 tons or 65% of rice seed demand in 2016/2017 (Napasintuwong, 2018). About 79% of farmers in the Northeast keep seeds for rice production in the next season, whereas only 10% of farmers in the Central region do so (Napasintuwong, 2018). Intermediary channels include small traders in local markets who buy and sell seeds in small communities.

The formal rice seed supply systems refer to the supply of seeds that have formal quality guarantees. Napasintuwong (2018) explains that these include the community rice centers, agricultural cooperatives, private seed companies, and public seed enterprises, and altogether provide 35% of the total demand for rice seed in Thailand. The Rice Department has 23 rice seed centers that produce about 81,900 tons of rice seeds nationwide, which are sold at a controlled price. In 2016/2017, there were about 1,650 Community Rice Centers (CRC) which were producing 82,500 tons of rice seeds, and about 64 agricultural cooperatives nationwide engaged in rice seed production which contribute about 37,000 tons of rice seed supply. The supply of seed by over 200 private companies amounted to approximately 150,000 tons. The Rice Department developed a GAP standard in 2014 for rice seed, which is voluntary. Other certified seed systems include Geographically Indicated rice seed and organic rice seed.

A wide diversity of rice varieties is still grown in the country[8], however only a limited number of seed varieties are promoted for commercial production. Modern high yielding varieties, accounted for 55% of Thailand's 2013/14 paddy production (Rerkasem, 2017). Rice varieties developed and promoted by the national rice breeding program of the Rice Department include RD6, RD15[9], RD21 and RD43. Local traditional varieties currently account for 4% of all rice grown in Thailand (Rerkasem, 2017)[10]. Many of these local varieties are highly adapted to local conditions, and some are known to be rich in micronutrients such as iron and zinc (Prom-u-thai & Rerkasem, 2004; Saenchai et al., 2012; Jaksomsak et al., 2015; Jamjod et al., 2017, cited in Rerkasem 2017). New varieties such as "Hom Nin" and "Riceberry" are gaining in popularity. The typical rice varieties grown in the study area are Hom Dok Mali, RD15, Surin jasmine, and Jasmine Rice Chub Phae.

The application of chemical inputs is common in conventional rice cultivation. Thai agriculture relies heavily on chemical pesticides and fertilizers to protect crop as well as to increase production yield and product quality (NIH, 2005 referred in Panuwet et al, 2012). The use of chemical fertilizer in Thailand has increased from 1.95 million tons in 2009 to 2.87 million tons in 2018. The overall import of herbicide, insecticides, and fungicides has increased from 117,815 tons to 198,317 tons from 2010 to 2017 (Department of Agriculture, 2020).

For rice cultivation, approximately 208 kg. of chemical fertilizers were applied per hectare in the nationwide, and about 180 kg per hectare in the Northeast of Thailand, (OAE, 2020). The most update information available on pesticide used for rice cultivation is that about 1.3 kg. of pesticides were applied for rice cultivation per hectare. Herbicides and insecticides are the main pesticides used for rice cultivation (Praneetvatakul et al., 2013). Thai farmers spend on average US$60 per hectare for pesticide expenditure. However, based on the survey described later in Part 4.6, conventional rice farmers in the northeast region of Thailand use fewer chemical

[8] Promsomboon and Promsomboon (Collection and Evaluation of Local Thai Rice Varieties (Oryza sativa L.) *Journal of Life Sciences* 10 (2016) 371-374) explored the biodiversity in Local Thai rice Varieties (Oryza sativa L.) during May 2011 to March 2013 by conducting surveys and collecting rice varieties from 4 regions of Thailand. They found altogether 89 varieties of local rice which include 16 in Central region, 12 in Northern region, 23 in Northeastern region, and 38 in Southern region. Among them were 21 varieties of glutinous rice and 68 varieties of non-glutinous rice. Ecological classification suggested 72 varieties of lowland rice, 10 varieties of upland rice, and 7 varieties of floating rice.

[9] RD6 a glutinous variety, and RD15 are developed from non-glutinous Hom Dok Mali 105 (Rerkasem, 2017)

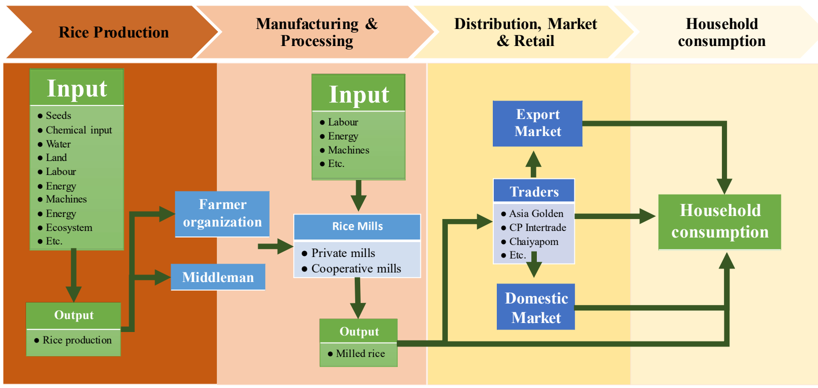
[10] Rekrasem notes that the area where local varieties are grown, "excluding those designated improved by plant breeding such as KDML105, RD6, and RD15, accounted for only 0.5 million ha of cropland in Thailand in 2013, down from 1.5 million ha in 1996" (OAEs, 1998; 2014).

herbicides and insecticides than the value from Praneetvatakul et al. (2013) with the average cost of $16.67 per hectare.

In Northeastern area, there are 2 main insect pests in the rice field, (1) rice gall midge and (2) brown planthopper. Other crop management problems include fungi and weeds. Agrichemicals are applied for pest control to control disease carriers, to control insects or animals that threaten production, processing, storage, transport, or marketing of produce, to protect commodities from deterioration (Kerdsuk et al, 2003). Chemical pesticides are applied in conventional rice production practices at different stages of production. These include antifungal agents such as mancozeb, carbendazim, kasugamycin, tricyclazole, isoprothiolane, propiconazole, flusilazole, tebuconazole, and hexaconazole (Rice department, n.d.). Herbicides regularly used include glyphosate, propanil, and butachlor (Rice department, n.d.). For insecticides, carbamate, abamectin, cypermethrin, carbofuran, and fumigants such as methyl bromide and phosphine are common substances used by farmers (Rice department, n.d.).

Other inputs in the initial stages of the rice value chain include, credit, machinery for land preparation, land rental, wage labor, family labor, and technical and traditional knowledge. Credit for rice farmers is mostly supplied by the Bank for Agriculture and Agricultural Cooperatives (BAAC) as well as agricultural cooperatives. Particularly, the agricultural cooperatives normally provide not only credit, but also supply other inputs and rice marketing channels. Small-scale machines such as irrigation pumps, power tillers, and threshers are normally utilized. The unique Thai tractor, long-handled two-wheel tractor, or walking tractor, were commonly used in Thailand for land preparation in the past. However, nowadays the medium-size tractor are starting to replace the walking tractor. Walking tractors are still used as power generators for water pumps and other equipment (Byerlee, D., et. al., 2013).

Figure 1.8 Thai rice value chain



Source: Modified from Byerlee, D., et. al. (2013)

In the study region, cultivation of a rice crop normally starts in the early part of the rainy season, around late June or early July. The rice grains will normally be ready for harvest around the end of October and early November, but in some cases, harvests may be reaped as late as the end of November, depending on date of planting, varieties of seed and climatic factors. Normally, farmers in Surin and Buriram plant only one rice crop per year.

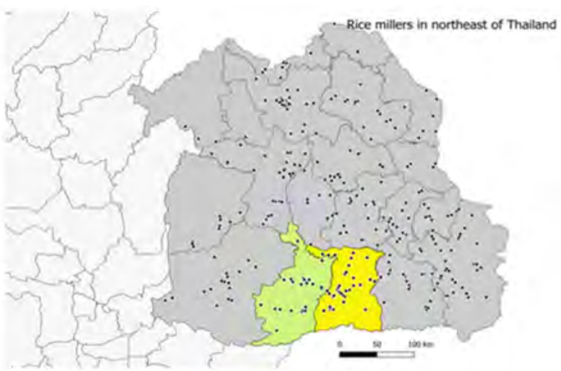
After harvesting, the rice is threshed, and grains are dried and stored. Many farmers have to sell rice soon after harvesting due to a lack, or shortage, of drying and storage facilities. They tend to sell at a low price as there is abundant rice supply during harvesting season in November and December.

Milling is the next step in processing to remove the husks from the grains. Farmers may sell rice directly to a mill, through a consolidator, or through cooperatives. According to the Ministry of Commerce, there are 430 rice mills located in the Northeast region of Thailand (see figure 1.9)[11]. The highest concentration of rice mills is in Surin, Ubonratchathani, and Buriram. Just in the two study provinces, Surin and Buriram, there are 87 rice mills or about 20 percent of all rice mills located in the Northeastern region. Rerkasem (2017) notes that the development of local, small- and medium-sized, modern mills has allowed farmers to enter the retail milled-rice

[11] There are about 4,000 rice mills in Thailand. Their milling capacity is around 120 million tons per year. The size of mills varies from village-level mills to a capacity in excess of 200,000 tons a year.

market and facilitated development of new branches of the value chain with the emergence of local specialty rice. Rice may also be transported to another region. For example, Jasmine rice from the Northeast may be brought to the larger mills in the Central area. Due to the excellent road network and inexpensive transportation cost, this costs about $0.05 per kilogram per kilometer.

Figure 1.9 Location of rice mills in northeast of Thailand, highlighting Surin and Buriram 2019

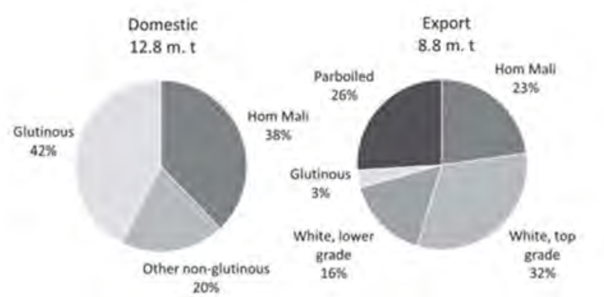


Source: Ministry of Commerce available from http://gis.dit.go.th/region

Rice of different types and grades are separately processed, stored, and marketed. In the mass market, milled rice is normally distinguished in the Thai market in four main categories that is, Jasmine, glutinous, parboiled rice, and “white” rice. The average of Thai in-season rice production from 2014 to 2016 was about 25 million tons (OAE, 2017) of which approximately 6.9, 6.8, 5.6, and 2.3 million tons were produced in the main season in the four main categories respectively (Rerkasem, 2017). The volume of rice traded domestically and via export, reported by Rerkasem (2017), was about 21.6 million tons. While jasmine rice is highly valued in both domestic and export markets, glutinous (“sticky”) rice is mostly consumed domestically, in the North and Northeastern regions.

Rice is commonly sold in bulk, without pre-packaging. In small provincial and district markets, as well as supermarkets in urban centers, however, consumers increasingly favour packaged and branded rice. Farmers are also beginning to retail their own produce through consumer and farmers networks and using social media connections (Rerkasem, 2017).

Figure 1.10 Main categories of Thai rice consumed in export and domestic markets



Source: Rerkasem, B. (2017)

Exports are important in the rice value chain. There are 200 members of the Thai Rice Exporters Association, of which around 50 companies are active, 30 of which share about 80% of total exported rice. In 2017, about 40 percent of rice produced in Thailand was exported, or a total of approximately 8.8 million tons. Forty eight percent of exported rice is white rice. Parboiled rice covers around 26 percent of total exported rice. Premium jasmine rice comprised about 23 percent of the total volume of exported rice (see figure 1.10 for more details). Thai rice is exported to over 100 countries around the world, particularly African countries, US, China, Japan, Hong Kong, and neighbouring countries in the South East Asian region (see Table 1.2). Exports to individual EU member nations are not in the top twenty export destinations, but when considered as a block, total exports of Thai rice to the EU amount to almost 250,000 metric tonnes which is the equivalent of 8th export destination of Thai rice (see Table 1.3). The destination of different categories of Thai rice is illustrated in figure 1.13.

Table 1.2: Top twenty Thai rice export destinations by volume, and value, 2020

Thai rice exports, top twenty destinations			
NO.	country	**quantity(tons)**	**value (million baht)**
	World	5,734,038	116,045
1	South Africa	672,777	9,925
2	U.S.A	672,183	21,892
3	Benin	484,290	7,012
4	China	381,363	8,427
5	Angola	347,292	5,182
6	Cameroon	273,922	3,929
7	Japan	257,677	3,608
8	Mozambique	194,981	2,793
9	Hong Kong	175,586	5,932
10	Singapore	127,296	3,923
11	Yemen	122,658	1,739
12	Canada	117,461	3,654
13	Senegal	106,822	1,539
14	Cote Dinoire	97,998	1,662
15	Togo	94,071	1,377
16	Australia	92,485	2,675
17	Indonesia	89,406	2,262
18	Congo, The Democratic Republic	89,220	1,248
19	Philippines	79,608	1,139
20	Malaysia	73,400	1,126

Table 1.3: Thai rice export destinations to EU by volume, and value, 2020

Thai rice exports to EU 2020		
Country	**Quantity(mt)**	**Value (million baht)**
United Kingdom	51,001	1.232
France	49.119	1,529
Netherlands	37,620	1,110
Italy	28,287	846
Belgium	27,423	669
Spain	13,817	328
Sweden	9,890	341
Germany	8,296	283
Poland	7,516	181
Czech Republic	4,426	146
Denmark	2,188	78
Finland	1,691	50
Ireland	1,557	57
Portugal	1,288	48
Lithuania	1,043	22
Greece	1,018	24
Malta	734	21
Cyprus	569	19
Austria	541	17
Hungary	318	9
Croatia	125	2
Bulgaria	75	2
Latvia	73	1
Estonia	53	1
Slovenia	25	1
Total EU	248615	7,015
World	5,734,038	116,045
	4%	6%

Source of data for tables 1.2 and 1.3: Information and Communication Technology Center, Ministry of Commerce, with cooperation of the Thai Customs Department, From http://www.thairiceexporters.or.th/export%20by%20country%202021.html
MT : Metric tons

The Ministry of Commerce has promoted Thailand as the ASEAN hub of organic farming and trade. While overall rice exports have fallen substantially in the last few years, organic rice exports have grown, with an increase of 77 % from 12,131 tonnes in 2017 to 21,553 tonnes in 2020. The value has more than doubled in that time, from 500 million Baht in 2017 to over a billion baht in 2020.

Table 1.4: Relative importance of Organic Rice Exports in Thailand

Organic rice exports as a percentage of total rice exports					
Quantity (kg)	**2017**	**2018**	**2019**	**2020**	**2021**
Total rice exports	11,674,331,363	11,232,176,273	7,583,661,548	5,724,681,480	1,778,262,419
Organic rice exports	12,131,888	15,252,433	15,504,581	21,553,071	11,139,786
%	0.10%	0.14%	0.20%	0.38%	0.63%
Value (baht)	**2017**	**2018**	**2019**	**2020**	**2021**
Total rice exports	175, 160,779,227	182,081,673,799	130,584,562,081	115,914,916,316	34,391,950,712
Organic rice exports	499,992,324	679,470,738	702,952,968	1,006,666,973	495,410,453
%	0.29%	*0.37%*	0.54%	0.87%	1.44%

Source of data: OAE 2021 extracted from statistics available from http://impexp.oae.go.th/ Figures for 2021 are from Jan to Jun

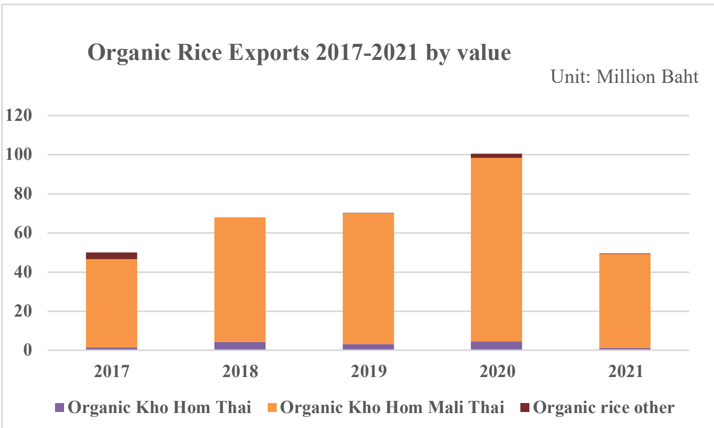
Thai organic rice exports are mainly comprised of the higher value aromatic rice varieties, including both Khao Hom Thai and Khao Hom Mali Thai (see table 1.5 & Figure 1.11 below).

Table 1.5 Types of Organic Rice Exports in Thailand 2017-2021

Value (Baht)	**2017**	**2018**	**2019**	**2020**	**2021**
Organic Kho Hom Thai	15,049,411	43,291,187	30,666,702	45,920,267	11,090,648
Organic Kho Hom Mali Thai	450,139,904	636,179,506	671,498,054	938,473,353	481,838,443
Organic rice other	34,803,009	450,000	788,212	22,273,353	2,481,362
Total	499,992,324	679,470,738	702,952,968	1,006,666,973	495,410,451

Source of data: OAE 2021 extracted from statistics available from http://impexp.oae.go.th/ Figures for 2021 are from Jan to Jun

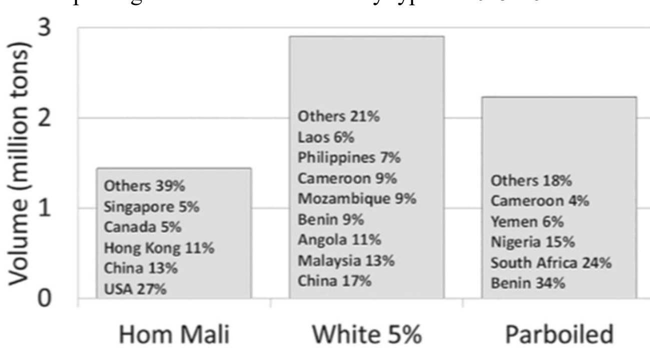
Figure 1.11: Organic Rice Exports 2017-2021 by value



Source of data: OAE 2021 extracted from statistics available from http://impexp.oae.go.th/
Figures for 2021 are from Jan to Jun

Due to limited data, the analysis in this study will mainly focus on components of the rice value chain within Thailand, including farm production, processing, milling, and domestic consumption.

Figure 1.12 Main importing countries of Thai rice by type in 2015-16.



Source: Rerkasem (2017) with data from OAE (2017).

Paddy rice production not only generates rice for consumption, but also provides byproducts and other relevant products that can be commercialized. The main byproduct from rice cultivation is rice straw, of which over 32 million tons could be generated a year[12] (DEDE, n.d.). The rice straw could serve as compost, cattle feed, mulch, paper pulp, as well as bioenergy.

The main byproducts from rice milling or processing are rice husks and rice bran. The quantity of rice husks generated is estimated at about 20-24% of rice production, or about 6 to 7 million tons a year. In the main, rice husks were used as bioenergy (Loy et al., 2018). The rice bran, estimated at about 8-10 percent of paddy rice or 2 to 3 million tons a year (Rice department, n.d.), is used as an input for the production of animal feed, cooking oil, supplementary food, and cosmetic products. Moreover, other relevant rice-based products are fresh noodles, dried rice noodles, rice flour, and as a raw ingredient in beer. However, for organic rice, to our knowledge, there is no data that can identify markets of byproducts from organic rice.

[12] The residue ratio of rice straw is one and the residue ratio of rice husk is 0.2 (Esa, N. M., Ling, T. B., & Peng, L. S., 2013)

Part 2 Overview of Thai policies related to the rice system

1. **Overall policy and strategic plans to develop agriculture and food in Thailand**

Since the first National Development plan in 1961, Thailand has emphasized both agricultural production and price support programs. The primary intention was to ensure farmer livelihoods and a prosperous agricultural sector for poverty reduction through improving agricultural productivity. During economic development in the 1990s, most agricultural policies were aimed to restructure the crop production systems by providing incentives for farmers directly to grow higher return crops as commodities instead of those with a declining price (e.g., rice, cassava). The agricultural policy in Thailand has shifted towards direct support for farmers. The first price support, Paddy Pledging Policy, was introduced in 2001/02, and the first farmer income guaranteed (rice, maize, and cassava) to pay farmers the difference between the guaranteed and market reference price in 2009[13].

Since 2005, the government has promoted Thailand as the "Kitchen of the world", supporting Thai agricultural produce to meet export demand. In 2017, Thailand ranked 12th worldwide for agricultural outputs overall, and has significant global food commodity exports of rice, sugar, cassava, chicken, seafood, and pineapple (BOI, 2020). During 2012-2016, Thailand's agriculture strategies focused on creating products and food to promote the high quality of Thai food and other agricultural products in particular in the international market[14]. Aiming to be a center of food trade and food production, the government aimed to increase crop production capability through research and development to improve crop varieties and production technology. Transferring such knowledge to farmers was the aim of the smart farmer campaign.

Thailand adopted the FAO framework of good agricultural practices (GAP) under the Agricultural Standards Act (2008)[15]. GAP aims to encourage farmers to produce agricultural products that are safe for consumers. Additional support for certified GAP Farmers is provided through the GAP+ program and GAP++program. This program is the extended version of GAP

[13] Poapongsakorn (2019). http://ap.fftc.agnet.org/files/ap_policy/1020/1020_1.pdf
[14] Government policies in the National Assembly, August 2011
[15] https://www.acfs.go.th/standard/download/eng/GAP_Food_Crop.pdf

and GAP+ to verify product quality, ensure farmers safety, and to certify the GHG emission reduction. GAP++ is promoted according to the Standard of the Sustainable Rice Platform (SRP) and currently support the progression under the Thai Rice NAMA project[16]. We discuss more details in the next section.

Recently, the agricultural sector in Thailand is primarily guided by Thailand's 20-Year National Strategy (2018-2037) becoming "a developed country with security, prosperity and sustainability in accordance with the Sufficiency Economy Philosophy"[17]. One aim is to enhance national competitiveness by upgrading agricultural productivity in terms of quantity and value, as well as product diversity within the following sectors: farming that reflects local identity, "safe farming", "biological farming", agricultural produce processing, and smart farming. The long-term 20-year National Strategy is used as a framework to establish separate five-year plans to lay a foundation for agricultural development at systematic growth. The Ministry of Agriculture and Cooperatives (MoAC) is playing a major role to prepare the 20-year Agriculture and Cooperatives Strategy (2017-2036) for the development of the agricultural sector[18]. With the National Reform Steering Assembly and the UN Sustainable Development (SDGs), the development plan envisions (1) Smart Farmers, farmers who are specialized in the profession; (2) Smart Agricultural Group, farmer institutions that are efficient in farm management; (3) Smart Agricultural Products, agricultural product quality that meets customer needs and standards; (4) Smart Area/Agriculture, for agricultural areas and sectors with potential for Smart Agriculture .

Five strategies are highlighted as follows:

(1) Strategy 1: strengthening farmers and farmer institutions, to promote a transition to Smart Farmers and Smart Groups, with Smart Enterprises; promoting pride and security in agricultural profession by applying technology and innovations in farm management.

(2) Strategy 2: Raising the productivity and quality standards of agricultural commodities by improving product quality and production efficiency, and by promoting agriculture throughout the supply chain.

[16] https://www.nama-facility.org/news/nama-facility-funding-approved-to-support-the-implementation-of-the-thai-rice-nama/
[17] National Strategy Secretariat Office, Office of the National Economic and Social Development Board., Thailand. https://www.moac.go.th/pyp-dwl-files-402791791893
[18] Ministry of Agriculture and Cooperatives. 2017b. The Twenty-year Agriculture and Cooperatives Strategy (2017-2036) Bangkok, Thailand. (in Thai)

(3) Strategy 3: Increasing competitiveness in agricultural sector based on technology and innovations guidelines by developing technology and innovation to drive forward the "Agriculture 4.0" and "Thailand 4.0" policies.

(4) Strategy 4: Balanced and sustainable management of agricultural resources and environment, focusing on sustainable management and conservation of agricultural resources.

(5) Strategy 5: Development of Public Administration System, aiming at developing all government personnel to become Smart officers and researchers, integrating the works of all agencies in all sectors using modern administrative system.

In late 2019, Thai parliamentarians led by a committee from MoAC set a target for 100 percent of agricultural land (149 million rai or 23 million hectare) to be cultivated using organic or sustainable agricultural practices by 2030.

2. Policies and initiatives to develop rice sector in Thailand

During 2017-2021, rice policies in Thailand mainly aim to help the development of farmers' well-being under the five-year strategy in response to Thailand 4.0 Agenda[19]. Regarding rice, policies under the Ministry of Agriculture and Cooperatives Plan can be summarized into two aspects; production and marketing policy.

For production policy, three main strategies are (1) Cost Reduction: reducing the costs of production and improving the quality of products. This is implemented through the Cost Reduction Operation Principles (CROP) initiative of rice together with GAP for rice farming. This was found to help to reduce 50-64% fertilizer inputs per season, maintaining yields during the dry season; as a result, increase in income for CROP adopters in the central plain area (Stuart et al., 2018).

(2) Land Zoning: A restructuring plan for optimizing the productive use of land. This determines which areas are suitable or unsuitable for growing a commodity, including rice, based on characteristics of the area, demand-supply of the commodity, and water resources[20]. Zoning can be used as a guideline for relevant organizations to adjust systematically to balance provincial demand and supply for agricultural products. The Economic Crop Zoning by Agri-map project is further described below.

[19] https://www.boi.go.th/upload/content/Thailand,%20Taking%20off%20to%20new%20heights%20@%20belgium_5ab4f8113a385.pdf

[20] Land Suitability Guidelines for Crop Commodities (2016), LDD Zoning, Land Development Department, MOAC (in Thai). http://e-library.ldd.go.th/library/Ebook/bib9829.pdf , http://natres.psu.ac.th/nsfc4/download/4.pdf

(3) Marketing: The policy to promote value-added products provides farmers with training opportunities and knowledge about rice processing, packaging, and branding development. Three strategies include to identify demand before planting season, establish an e-market platform driven by business promotion, and promote niche market products, including encouraging organic rice, geographic identification (GI) rice, nutritious rice, colored rice, and native rice varieties. An area-based extension approach is applied to implement the expanded million rai[21] of organic rice in 2020 as well as other agricultural food products.

Subsidy schemes of rice production

There are two main schemes implemented under various programmes by successive Thai governments to subsidise the production of crops, including rice and other common agricultural products, such as rubber, cassava, oil palm, and corn. The first scheme is known as the **farmers' income guarantee scheme**. In the crop season 2018-2019, the total amount provided for subsidies for rice farmers was approximately 24.8 billion Baht (about $0.826 billion). Under this scheme, rice farmers were granted 500 Baht (about $16) per *rai* per household, up to a maximum of 20 *rai* of rice land.

The second type of subsidy is **rice price guarantee scheme**. This subsidy is designed to help stabilize prices. The government agrees to pay farmers at fixed prices for a certain volume of rice production if the market price falls below the guaranteed prices during the harvest season (see below). The guaranteed price is discussed and agreed among stakeholders including government, rice farmers representatives, and rice processors. A total of 9.4 billion Baht was paid under this scheme to over 340 thousand households at the end of the first 2019/2020 planting season.

The insured prices for rice varieties are as follows:

- Jasmine rice - 15,000 baht per ton (maximum of 14 tonnes per household).
- Prathum Thani jasmine rice - 11,000 baht per ton (maximum of 25 tonnes per household).
- Glutinous rice - 12,000 baht per ton (maximum of 16 tonnes per household).
- Non-glutinous rice - 10,000 baht per ton (maximum of 30 tonnes per household).

Subsidies for organic rice farming are discussed later in this section.

[21] 160,000 hectares

Mega Farm project - Rice Mega farm

The Rice Mega Farm scheme of the Ministry of Agriculture and Cooperatives (MoAC) has operated since 2017 and now covers 1.05 million rai of rice farmland. The aim is to encourage participating farmers to pool their rice farmland into one large plot (consolidating several individually-owned landholdings under a single management structure) to improve economies of scale including in farm planning, product marketing and distribution. The integration of knowledge and resources in a mega farm aims also to improve strategic planning and increase farmer's bargaining power and develop farm efficiency. Under the project, modern equipment, including harvesting machinery, is made available to farmers. Moreover, farmers, rice mill operators and exporters are matched to produce rice to meet market demand.

Economic Crop Zoning by Agri-map

The Economic Crop Zoning by Agri-map is a collaboration between the Office of Agricultural Economics (OAE) and Land Development Department (LDD), which aims to define suitable areas for cultivating cash crops according to economic and social criteria, to establish a database for economic crop planning and policy support, as well as to support provincial level action planning for communities. The evaluation of suitability is based on information on physical characteristics, including present land-use, forestry boundary, soil properties, precipitation, irrigation availability, and crop growth requirements to estimate suitability level for rice production. Each degree of suitability is expressed in terms of potential productivity, that is average tons per hectare (tph), ranging from the most suitable (S1: greater than 4.126 tph), moderately suitable (S2: 3.126 – 4.125 tph), marginal suitable (S3: 2.5 – 3.125 tph), and unsuitable (N: less than 2.5 tph). Production efficiency and improvement of product quality are emphasized.

The restructuring program also promotes the introduction of other cash crops to replace the second rice crop during the dry season. In areas considered unsuitable for rice growing, a mix of crop farming, or raising livestock are promoted. The direct subsidies paid out via the BAAC (equivalent to about USD 74.6 million), provided each registered household with 5,000 Baht per rai for building irrigation systems, and 2,300 Baht to raise fish, and 2,800 Baht to invest in livestock raising[22].

[22]However, several implementation issues regarding, in part, suitable specifications and accuracy of land identification and extent has impeded many farmers to join the program.

Initiatives to promote sustainable rice production

According to the vision of the agricultural development plan under the 12th National Economic and Social Development Plan (2017-2021), the MoAC has been promoting resource-use efficiency and climate change resilience in agricultural production, and particularly, the adoption of sustainable agricultural practices in an area of 10 million *rai* (1.6 million ha) by 2021. The first pilot project on sustainable agriculture in 2005 was approved with a budget of 15.8 million USD for 3,500 smallholder households to strengthen and improve sustainable agricultural development.

The Thai government is collaborating with a number of projects to promote a more sustainable practices in rice production, in connection with the Sustainable Rice Platform (SRP). The SRP initiative[23] developed the world's rice sustainability standard, and performance indicators for rice cultivation. This provides a normative basis framework for supporting claims to sustainable performance in rice value chains which bridge between global standard and local field application. Together with the Better Rice Initiative Asia (BRIA) project, ASEAN Sustainable Agrifood Systems[24], the Rice Department has carried out pilot testing of the SRP Standard in the northeastern province, of Thailand. Under this pilot scheme, farmers from the Community Rice Center of Bua Ngam and Klang villages, Det Udom District, in Ubon Ratchathani have been certified as working towards sustainability, according to the SRP Standard.

The Rice Department is also collaborating with private sector groups through the Sustainable Aromatic Rice Initiative (SARI) – Thailand to grow aromatic rice in a more responsible manner in the Tung Kula Rong Hai area of Roi Et province.

The SRP Standard is a tool for wide-scale adoption of best practices in eight themes: farm management, land preparation, water use, nutrient management, integrated pest management, harvest and post-harvesting, health and safety, and labour rights. The achievement of each SRP

[23] The sustainable rice platform (SRP), an international multi-stakeholder alliance led by UNEP, IRRI, and GIZ, mainly promotes resource use-efficiency and climate change resilience in rice systems through entire value chains. The SRP aims to develop voluntary market transformation in a global rice sector with sustainable standard, improved livelihoods for rice smallholder farmers, and reduced negative environmental externalities of rice production.
http://www.sustainablerice.org/assets/docs/SRP%20Performance%20Indicators%20for%20Sustainable%20Rice%20Cultivation%20(Version%202.1).pdf

[24] https://www.asean-agrifood.org/sustainable-rice-platform-standard-the-worlds-first-sustainability-standard-for-rice/#

requirement is evidenced by one or more of the SRP performance indicators (PI), designed to assess sustainability. In relation to promoting biodiversity and reducing greenhouse gas emissions, the requirements of the Standard focus on the prohibition of both conversion of environmentally sensitive areas[25] and intentional introduction of invasive species, the maintenance of site-specific biodiversity and ecosystem services, water and nutrient management, including alternate wetting and drying where possible, integrated pest management, choice of fertilizer, and post-harvest management (e.g., sustainable drying techniques, no burning of stubble or straw to mitigate GHG emissions).

The System of Rice Intensification (SRI) has been introduced and promoted in Thailand by various research agencies, civil society organizations and government departments[26]. The Ministry of Agriculture and Cooperatives (MoAC) has been supportive of these activities, acknowledging that SRI can aid sustainable rice production in Thailand. SRI cultivation is focused on integrated approach to rice production that includes six core practices including transplanting of seedlings at a young age, low seedling density with shallow root placement, wide plant spacing in a square grid, intermittent flooding, frequent weeding, preferably with a mechanical weeder, and finally incorporation of organic matter into the soil, complemented by synthetic fertilizer if needed. SRI has been found to raise the yields of traditional local varieties so that they can be competitive economically with improved varieties, which helps to conserve rice biodiversity. The project was implemented in food-insecure areas of Surin, Uttaradit and Sisaket provinces and has encouraged Farmer Participatory Action Research (FPAR) activities for promoting location-specific adaptation of SRI practices. Some of the positive results highlighted through FPAR include greater abundance and activity of soil biota, crops were more resilient to drought and flood so that pests and diseases are reduced[27].

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[25] For example, the rice farming area requires not causing conversion within a (proposed) protected area, key biodiversity area, primary forest, and other natural ecosystems after 2009.

[26] Particularly through the SRI-LMB project coordinated by Asian Institute of Technology (AIT), Asian Center of Innovation for Sustainable Agriculture Intensification (ACISAI) in partnership with FAO, Oxfam, the SRI-Rice Center at Cornell University, and the University of Queensland, together with many national partners coming from ministries, national universities, and NGOs. http://www.sri-lmb.ait.asia/ .

[27] According to a policy note produced by the project, positive impacts of FPAR project experiments involving 5,065 farmers 2014-2016 were observed in SRI fields on crop productivity (increased 19%), profitability (3 times), labor productivity in rice production (increased 80%), water productivity (kg of rice per m3 of water), less GHS emission from rice fields due to less fertilizer (26%). FPAR farmers experienced in resource usage of less seed (79%), less energy (52%). http://sri-lmb.ait.asia/country/doc/Thailand%20Policy%20Note-Final.pdf

Organic rice policy and development programs

The National Organic Agriculture Development Strategy (2017-2021, BE. 2560-2564) promotes the organic agricultural productivity and the development of Thailand's organic products. The goal is to achieve at least 200,000 rai of organic agriculture area per year to reach one million rai of organic agricultural land by 2021. Currently, the total area of land under organic farming is 570,409 *rai* (91,265 hectare), the majority of which, 59%, is dedicated to producing organic rice[28].

The Ministry of Agriculture and Cooperatives (MoAC) has started a pilot project named the "Million Rai Organic Rice Farming" to persuade conventional rice farmers to switch to organic rice farming. The primary objectives of this program are to promote organic rice production based on the organic rice standard of the Rice Department and to increase the area suitable for organic rice production that qualifies for the Organic Thailand certificate.

The organic rice production program (2017-2021, BE.2560-2564) is hosted by the Rice Product Development Division of the Rice Department and is to be implemented in all 77 provinces across the country. The target of program was to encourage farmer participants to increase their cultivation area to achieve a million rai of organic rice production by 2019. Since it is common for rice yields to decline in the early stages of transition from conventional to organic practices, the government provides a funding subsidy of 2,000 – 4,000 baht per *rai* for each qualified farmer who adopts organic rice cultivation practices, every year for the first three years. In the fourth year, the rice product is eligible to apply for certification by the Organic Thailand scheme run by the National Bureau of Agricultural Commodities and Food Standards (ACFS). The expenses associated with farm inspection and certification are covered for the next two years. Qualifying farmers are also eligible to receive organic rice seed for planting each year, to a maximum of up to 15 *rai* (roughly 2.4 ha) per farmer, for a total of three years.

Farmers who are interested in participating in the program to promote organic rice farming must follow these guidelines[29]:

1. Farmers must form a group with a minimum membership of five farmers. The group and its members must be approved by a provincial Commission.

[28] June 2019 (OAE). Other common agricultural products supported through the strategy include cassava, sugar cane, and soybean.
[29] http://www.ricethailand.go.th/web/images/brpd_rd/OrganicProject/1.application_organic_project_2561.pdf

2. Their combined farmland must cover at least 100 *rai* (16 hectare), located in the adjacent land or within the same community or district.
3. The member's farmland characteristics must be appropriate for growing organic rice and must be approved by an official for use for growing organic rice, for example organic farmers have to dedicate 1-2 metres of land around their rice fields as a buffer boundary to protect from airborne contamination from other agricultural fields.
4. Each property must have access to natural water resources (e.g., rainfall), or other water resources for rice cultivation, such as irrigation (eg from a pond, a well, or canal) which are not contaminated.
5. Farmers must think of effective ways to grow organic rice and maintain the quality of standard.
6. If a group quits organic farming after getting the bonus from being part of this programme, it will be prohibited from reentering in this program again.

Farmers are responsible for all costs to meet the above criteria for organic rice field qualification. For example, a cost related to create and manage a buffer zone. However, the requirement to ensure a dedicated water source for organic rice cultivation seems does not appear to be enforced. The cost of investing in water harvesting systems is not subsidized, so not all organic paddy fields can access to irrigation. If the area does not have access to irrigation, farmers depend only on the rainfall or public / community water resources. Farmers who can afford this investment will have their own pond. The financial support will be allocated after qualified for the program standard.

To be certified with the "Organic Thailand" standard, farmers must maintain the quality of rice carefully according to Thailand Agricultural Standards[30] for Organic rice. These were developed in 2003 and updated in 2010 and provide a detailed set of requirements for organic rice production. All the requirements for organic rice production must comply with ACF standards[31], to be certified with the Organic Thailand label. The organic product is verified through the inspection and certification systems relating to production, processing, labeling, and claims for

[30] https://www.acfs.go.th/standard/download/eng/ORGANIC_RICE_part4.pdf
[31] ACF inspection and certification systems at https://www.acfs.go.th/standard/download/eng/TAS-9000.pdf

organic products. The process of verification is operated by the government, private sector, or agencies that are accredited by MoAC.

Program support is offered at three stages in the transition from conventional to organic production system as follows:

1. The preparation stage (T1): This is the starting stage where members in the group have no prior experience of organic agriculture, and have not yet established formal group internal control system (ICS), but have committed to enter the programme.
2. The transition stage (T2): This stage is reached when members of the groups have been assessed to have begun applying organic practices in their farms, and a formal group ICS has already been established. Groups at this stage have not yet been certified to comply with the organic rice standards.
3. The qualified stage (T3): This stage refers to a qualified group of farmers whose rice products have recently been certified to comply with organic rice standard(s). In addition, T3 groups are further supported in partnership with a domestic entrepreneur.

The MOAC also provides export guarantees for produce that has been certified with the organic Thailand label. The label of Organic Thailand is provided for organic certified which produced for export.

Loans for Smart Farms and organic agriculture farming

The Bank for Agriculture and Agricultural Cooperatives (BAAC), founded under the Ministry of Finance, provides financial services directly and indirectly to farmers. According to the National Organic Agriculture Plan, the BAAC aims to lend 100 billion Baht to expand smart farmer model to 4,500 communities nationwide. A total of 928 communities have obtained credit funds through this scheme. The bank offers low interest rate loans for farmers to invest in farming, as well as loans for supplementary occupations such as organic fertilizer pellet manufacturing[32]. Farmers pay interest rate at 2% per year while the government and the bank absorb the remaining cost of borrowing.

[32] https://www.bangkokpost.com/business/1792329#cxrecs_s

Green Credit is another BAAC project to promote and support green loans. A total lending budget of 5,000 million Baht has been made available under this scheme to people with low income who want to improve their production and skills in organic and sustainable agricultural practices. The program offers low-cost loans to organic farmers whose produce has been certified under the Organic Thailand program and who have been certified as using only renewable energy (e.g., replace fossil fuels with bio-energy). Loans are available for individual farmers, community enterprises, farmer groups or cooperatives with an interest rate of 1% per annum (MRR-1) for typical individual farmers and 0.5% per annum for agricultural cooperatives or community enterprise (MRR-0.5)[33].

3. Relevant health and food safety policies and initiatives

Thailand's strategic framework for food management (2017–2021) aims to produce sufficient food to sustain domestic demand, support access to adequate food at all times, improve food quality, reduce food waste and use food correctly, promote sustainable food production, and support the development of food security and nutrition.

Thailand Healthy Lifestyle Strategic Plan (2011-2020) aims to promote eating habits that avoid overweight, obesity, and other food disorders[34]. The 20-Year National Strategic Plan for Public Health[35] (2017-2036) has a primary plan to prevent disease and, to reduce health risk factor by promoting and developing food safety standards. The workplan encourages business operators to produce food products that meet international standards. The government also promotes the public awareness of safe food and certified agricultural products that directly link to consumer health in order to change public attitudes and consumer behaviors. The health policy relating to the safety of agricultural food is also aligned with the agricultural pesticide regulations.

Agricultural pesticide regulations

The primary legal instrument for chemical pesticide management in the Thai agricultural sector is the Hazardous Substance Act (HSA) 1992 (B.E. 2535) (latest amended 2019[36]) which regulates

[33] https://www.baac.or.th/th/media.php?content_id=14262
[34] Moreover, regarding nutrition, the Government developed the Nutrition Action Plan in 2009.
[35] Strategy and Planning Division, Office of the Permanent Secretary, Ministry of Public Health (2018) http://164.115.27.97/digital/files/original/2ddc0ac1ececa4c666af70165c23e011.pdf
[36] Approved by the National Legislative Assembly on February 1, 2019. Unofficial translation at https://www.jetro.go.jp/ext_images/thailand/pdf/HazSubAct_20190201NLAapproved.pdf.

all-hazardous chemicals, including pesticides. The Act regulates the importation, use, marketing and possession of all-hazardous chemicals. Moreover, it aims to prevent toxic exposure to humans, plants, animals, and the environment. The National Hazardous Substances Committee, which is the comprised of representatives from the Ministry of Public Health (MoPH), the Ministry of Industry (MoI), and MoAC, is responsible for pesticide regulations.

Three pesticides are being given greater attention from society due to their widespread used in agricultural activities and high toxicity. These substances are paraquat, glyphosate, and chlorpyrifos. Glyphosate and paraquat, which are herbicides, are the top two agrichemicals imported to Thailand in term of both quantity and value. The number of reported cases of pesticide poisoning has been found to increase during the rice cultivation season between May and August each year (Tawatsin et al., 2015).

The National Hazardous Substances Committee decided in 2019 to ban paraquat and chlorpyrifos with effect from June 1, 2020, while the use of Glyphosate is restricted under certification only. The glyphosate can be used in certain agricultural activities, including conventional rice cultivation, as long as this is approved and supervised by local authorities.

Strategies of the Department of Agriculture (MoAC) to reduce the use of pesticides include launching mitigation campaigns including organic farming, integrated pesticide management (IPM), good agricultural practice (GAP), and promoting the use of bio-pesticides (Panuwet et al, 2012). The Ministry of Public Health's Food and Drug Administration (FDA) and Department of Medical Sciences (DMS) have responsibilities to carry out tests on food products for compliance with maximum limits of chemical residues for the purposes of ensuring food safety for Thai consumers and for export markets.

Promoting organic agriculture through public procurement and vocational education

The National organic agriculture development strategic plan promotes the accessible market channel in the community for local certified organic products. The objective is that the public hospital and schools should provide and acquire agricultural food products and raw materials for patients and students. This goal is implemented in such a way that every province in a local district arrange a specific public area where consumers and farmer can directly meet.

The Thai Health Promotion Foundation[37] is supporting a project to stimulate the organic market that provides an opportunity for local organic rice farmers and green market networks. Both hospitals and schools are used as weekly marketplaces[38].

4. Environment initiatives related to rice production

The Bio, Circular and Green Economy (BCG) roadmap was formally adopted in 2021 as a national agenda to be implemented by all related line Ministries in Thailand over the next five years, in line with established government priorities and national strategies, in particular the Thailand 4.0 initiative. Within the food and agriculture sector, the focus lies on developing high value and novel food products and functional ingredients, on biorefinery development, waste reduction, improvements in resources and land-use efficiency, and on smart and precision farming (e.g. new plant breeding techniques for coping with drought, flood and insect resistance). Within the biochemical sector, raw agricultural products including rice husks are targeted for use to produce polylactide for manufacturing bioplastic products which are currently among the country's top exports items[39]. Organic farming and improved rice seeds are showcased in the NTSDA website as examples of the BCG economy projects[40].

Being highly vulnerable to the impacts of global warming, Thailand attaches great importance to the global efforts to address climate change. The Climate Change Master Plan 2015-2050 (National Strategy 2018-2037) reflects Thailand's strategy on climate change mitigation and adaptation.

Overall, Thailand's GHG emissions amount to less than 1% of global emissions. The agriculture sector is the second largest source of emissions in Thailand, representing 14.72% of national emissions in 2016. Rice production is both an important sink for the sequestration of carbon dioxide from the atmosphere and an important source of GHG emissions, particularly methane. Methane is generated through anaerobic decomposition of organic matter in flooded paddy fields, and persists in the atmosphere for approximately a decade. Over large areas, rice cultivation contributes a significant quantity of this highly potent, if short-lived, greenhouse gas.

[39] https://www.boi.go.th/upload/content/TIR_Newsletter_June2020.pdf
[39] https://www.boi.go.th/upload/content/TIR_Newsletter_June2020.pdf
[39] https://www.boi.go.th/upload/content/TIR_Newsletter_June2020.pdf
[40] https://www.nstda.or.th/thaibioeconomy/project-showcase/national.html

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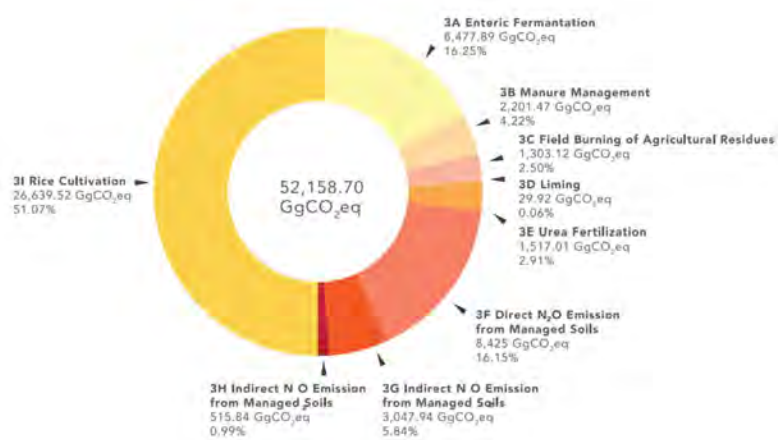
Rice cultivation was the main contributor to GHG emissions in Thailand's Agriculture sector, at 51.07% of agriculture sector emissions in 2016 (ONEP, 2020)[41]. Emissions from rice cultivation in Thailand have not increased significantly over recent years, from an estimated 26,553.26 GgCO2 eq in 2000 to 26,639.52 GgCO2 eq in 2016[42].

Figure 2.1 GHG emissions in Thai Agriculture sector 2016,



Source: ONEP, 2020

Thailand's Nationally Determined Contribution (NDC) Roadmap on Mitigation 2021-2030 does not currently include agricultural sector targets. Potential alternatives for the rice sector to contribute to sustainable mitigation and adaptation to climate change are being explored through programmes such as the Rice NAMA project described below, and in the recently launched FAO project on Scaling up Climate Ambition on Land Use and Agriculture through Nationally Determined Contributions and National Adaptation Plans[43] (SCALA).

Considering mitigation and adaptation policies related to rice production in Thailand, the Office of Agricultural Economics aims to encourage farmers to adopt climate-smart agriculture.

[41] https://unfccc.int/sites/default/files/resource/BUR3_Thailand_251220%20.pdf
[42] Ibid. Table 2-3: Key category analysis for the year 2016: Approach 2 – Trend assessment
[43] https://www.fao.org/in-action/scala/countries/thailand/en

This aims to ensure that farmers can 1) achieve sustainable productivity, 2) adapt and be resilient to climate change, 3) reduce GHG emissions, 4) prevent environmental degradation, and 5) maintain food security for society. These objectives also correspond to the Farming 4.0 Policy and the MoAC 20-year National Strategic plan.

Adaptation strategies will be of increasing importance as climate change presents serious threats and challenges to the development of agriculture in Thailand, especially rice production (Sekhar, 2018). At higher temperatures, rice produces less, or no, grain (Nguyen, 2005). Rice yields in the dry season could be reduced by 10% as a result of a 1°C rise in night-time temperatures (Peng, et al, 2004). A recent case study applied five climate models to assess emission scenarios RCP 4.5 and 8.5 in various sites around Thailand; most projected that rice yields will decrease during 2006-2040 (Jintrawet et al, 2017) as a result of changes in rainfall patterns and increasing temperatures.

Approximately 80 % of the area of Thailand's rice fields are rainfed (Suwanmontri et al, 2021), and thus are vulnerable to uncertain or untimely rainfall. In areas served by irrigation, competition for water resources is high and expected to increase. In recent years, drought has affected Thai agriculture, and restrictions have been placed on the amount of irrigation resources released for rice farming (Ngammuangtueng, 2019).

Lowering emissions in rice production

The government's Thai rice Nationally Appropriate Mitigation Action (Rice NAMA) project in collaboration with GIZ (2018-2023) aims to help farmers from Chainat, Ang Thong, Prathum Thani, Suphan Buri, Ayutthaya and Sing Buri provinces in the central part of the country to start applying low greenhouse gas emission methods. New farming techniques are promoted such as laser land leveling, alternate wetting and drying technique, reduction in water use, and the use of organic fertilizer, to lower emissions and apply best practices in sustainable rice production. It is expected that farmers will generate greater income by managing inputs more effectively and engaging with a growing market for sustainable rice. The project promotes the use of the BAAC's Green Credit program for private sector to invest in mitigation technology services to farmers such as land laser leveling, alternate wetting and drying, site-specific nutrient management, and straw/stubble management.

Additionally, the Thailand Greenhouse Gas Management Organization (TGO) has developed the Thailand Voluntary Emission Reduction Program (T-VER) to promote participation in the voluntary emissions reduction, to encourage domestic carbon markets to supply carbon credit trading in the future. Organic rice farming can attract certified carbon credits through the T-VER program, under the category of "Good Fertilization Practice in Agricultural Land". The T-VER scheme has provided financial incentives to encourage organic farming in Maha Sarakam and Nakhon Pathom provinces[44].

Biodiversity conservation in rice fields

The government's Rice Genetic Conservation Centre was set up in 1981 to manage and keep the stock of National Rice Seeds at the Pathum Thani Rice Research Centre. This aims to collect, conserve and utilize the rice genetic resources. So far, the Centre has collected over 20,000 sample of rice seeds. Independently, local farmers preserve and exchange rice seeds as a traditional practice, which helps to maintain heirloom varieties as well as on-farm seed diversity and crop resilience.

As acknowledged in the 6th national report on the implementation of the Convention on Biological Diversity[45], cropping systems of Thailand have been dominated by monoculture, such as rice intensive farming in central plains, with long-term negative impacts on the ecosystems and biodiversity. Several government initiatives, outlined in this report, indicate shift towards sustainable agriculture, which is better for both the environment and people's livelihoods. Thailand has been implementing the 4th Master Plan for Integrated Biodiversity Management (2015-2021) in collaboration with 4 major government agencies: the Ministry of Natural Resources and Environment, the Ministry of Agriculture and Cooperatives, the Ministry of Public Health and the Ministry of Science and Technology. The Department of Agriculture promotes sustainable use of Biodiversity in agricultural sector through "Agroforestry" and "Sustainable Agricultural System" especially in the buffer zone around protected areas. Guidelines for sustainable agriculture emphasise use of "the benefit of biodiversity to create the variety of

[44] Sarinee Achavanuntakul and Witoon Panyakul. (2016). Financial Incentives to Encourage Organic Farming in Thailand: Final Report Submitted to Rockefeller Foundation.
[45] https://www.cbd.int/doc/nr/nr-06/th-nr-06-en.pdf

activities in agricultural production in the field and blend these production activities to maximize the mutual benefit, natural pest control, and create various chemical free activities".

One relevant initiative to promote biodiversity in rice producing areas is the Eastern Sarus Crane Reintroduction Project[46] which aims to save endangered species while maintaining the productivity and sustainability of production landscapes. It is a collaboration between community-based organizations, local and international government agencies together with local farmers. The world's tallest flying bird, the Eastern Sarus Cranes nest on wetlands, and the cranes will nest in rice paddy fields if alternative wetlands are not available. The Sarus Crane reintroduction program was initiated by the Zoological Park Organization in collaboration with the Department of National Parks, Wildlife, and Plant Conservation and has been successful in breeding and reintroducing Sarus cranes back into the wetlands of the Huay Chorakhe Mak Non-hunting area, Buriram Province. Since the Huay Chorakhe Mak Non-hunting area is surrounded by rice paddy fields, the Zoological Park Organization and partner organizations have encouraged and incentivized farmers around this area to switch from conventional rice practice to organic practice. This is to make sure this rice paddy area is suitable for the crane to live and reproduce. After some local farmers have adopted organic rice cultivation in accordance with the National Strategy on Organic Farming and Participatory Guarantee System (PGS), the number of the bird species' nest sites is increasing.

Water and air pollution regulations related to rice production

The Pollution Control Department (PCD), Ministry of Natural Resources, and Environment is in charge of managing pollution problems in Thailand and collaboration with other agencies and networks. Expected outcomes of the PCD's Pollution Management Plan 2017-2021 and 20-year strategy include the control, minimization and management of hazardous chemicals in the agricultural sector. Regulations relevant to rice production focus on controlling waste generated from sources (domestic, industrial, and agricultural sectors).

For surface water quality, after 2009, the use of chemical fertilizers, insecticides, herbicides, and other pesticide substances in rice fields are monitored for contamination into water bodies.

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[46] https://undp-biodiversity.exposure.co/cooperation-for-coexistence?fbclid=IwAR2cEuBtqgiRc0fZK9DkFR4aXFg8l5hk-tky4MV-a0C-4SOrkd5MAdhmgPM
ONEP: http://www.onep.go.th/ebook/ne/ne_2562_3.pdf

For air quality, the Pollution Management Plan serves as a guideline for reducing open burning and to promote alternative methods for agricultural residue management. The PCD collaborates with local administrative organizations. Farmers are subsidized for adopting soil equipment and farming technology to reduce the burning of crop residues.

Moreover, the Department of Alternative Energy Development and Efficiency, Ministry of Energy has implemented a renewable energy plan to encourage the use of agricultural residues as a raw material for heat and electricity production[47].

The strategic plan for the development of organic agriculture is formulated by MOAC in part to protect the soil and water quality of agricultural areas. The support for farmers who adopt sustainable rice cultivation practices aligns with the support programmes for agricultural zoning and irrigation.

[47] Department of Alternative Energy Development and Efficiency (DEDE). Alternative Energy Development Plan: AEDP2015; Bangkok, DEDE: Thailand, 2015; pp. 1–20. Available online: http://www.eppo.go.th/images/POLICY/ENG/AEDP2015ENG.pdf (accessed on April 9, 2020).

Part 3 Development of scenarios for assessment

Scenario analysis can be a very powerful tool in the decision-making process. It allows to see in the future the environmental and economic impacts of the actions that are taken in the present. Indeed, to compare how different actions in the present can affect the future, TEEBAgriFood Thailand build different scenarios.

Scenario analysis differs from conventional forecasts in that we not only try to predict a probable future, but we actually want to compare different plausible policy futures. Indeed, tackling pressing political issues requires imagining different future outcomes and acknowledging their trade-offs.

The scenarios developed under TEEBAgriFood Thailand will provide information on the comparative change of the stocks of natural, social and human capital in different scenarios. In other words, the scenarios allow the analysis of marginal changes over time, that is, for example, how the provision of ecosystem services for human well-being will change by 2035 compared to today.

The questions to be explored are:

- What are the values provided by nature, people and society to rice production under different rice policy interventions options?
- What are the often-neglected impacts and dependencies that rice food systems have on nature, people and society?
- What are the costs and benefits in terms of natural, social and human capital through different policy interventions scenarios aimed at increasing organic rice production and consumption, including the Rai Organic Rice Development project the Parliamentary targets for Organic Agriculture Development by 2030?

Through these questions the research team will explore the invisible benefits and costs across the rice value chain, as well as the linkages of rice production to the health of both farmers and consumers.

The methods by which ecosystem services are being measured and valued are summarized in the Methodologies report. The research team has analyzed the benefits and costs of different rice production systems through a comparison between three different plausible future policy scenarios. The scenarios examined are further presented below. The above questions and the scenarios outlined below were put forward for consultation with the TEEBAgriFood Steering Committee as part of the process of their development.

The definition of scenarios is required to ensure that the questions analysed through the research directly respond to the policy questions put forward by the government and other stakeholders. Initially, the scenarios have been defined based on the government's policy and target. A focus group of local stakeholders in study sites, including local agricultural officers, farmers, millers, merchants, agricultural banks, and farmer organization heads were invited to reflect on major concerns related to the development of the organic agriculture sector.

The best data and models are worth nothing if you cannot tell a story that resonates with decision makers. Therefore, scenario development is an iterative process, involving decision-makers throughout. The definition of scenarios presented below are designed to reveal the costs and benefits in economic terms of the current and possible policies for promoting organic rice production. The timeframes presented in the scenarios below, will allow the estimation of the extent of economic costs and benefits as the areas of organic farming increase as they change over time in the near, medium, and long term.

Scenario development

Based on plans and policies outlined in the section above, including the Million Rai Organic Rice Farming pilot project of the Ministry of Agriculture and Cooperatives (MOAC) (2017-2021), and Thailand's 20-year strategic plan (2017-2036), which includes a plan for developing Thailand's organic products, the research team propose a 15 year time frame for scenario analysis, starting in 2020 and ending in 2035. Differential costs and benefits that arise from a change in land use according to each scenario below will be examined over the short, medium and long term. This will allow the research to weigh short term costs and benefits against longer term costs and benefits. These timeframes will be defined as the period from 2020-2026 (short term costs and benefits), 2020-2030 (medium term costs and benefits), 2020-2035 (long term costs and benefits).

As explained in Part 4, it is assumed that there will be no expansion or contraction of the rice growing area over the period 2019-2035. The projections of land conversion to organic rice are modelled exclusively in the areas which are currently growing rice using conventional methods. Organic rice would not be predicted to expand into areas which are currently used for growing other crops, forests, wetlands or other current land uses.

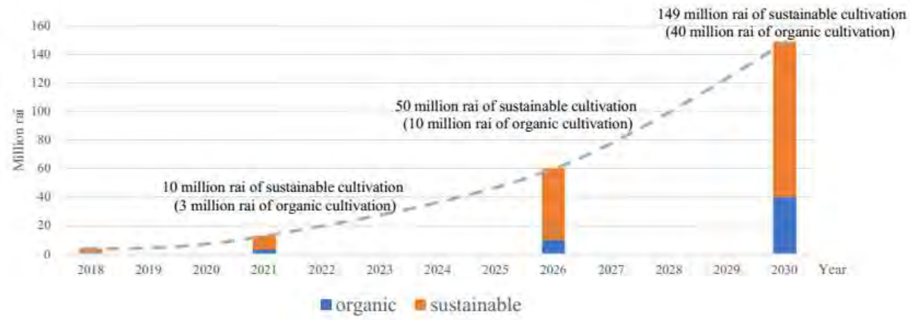
Of relevance to this timeframe are two policy targets. The first is the organic rice production program target of the Rice Department to be implemented in all provinces across the country to encourage farmer participants to increase their cultivation area to achieve 1 million rai of organic rice production by 2019. The target is to sign up farmers who are committed to transition to organic rice production by 2021. The transition period is expected to be 3 years, such that the target of 1 million rai of organic rice area should be reached according to the programme by 2024.

The second is the unanimous vote by Thai parliamentarians on (date) to set a target for 100 percent of agricultural land (149 million rai or 23 million hectare) to be cultivated using organic or sustainable agricultural practices by 2030. Intermediate spatial targets have been set progressively, such that by 2021, 2 percent of agricultural land (about 3 million rai 0.48 million hectare) should be under organic agriculture, and approximately 7 percent of agricultural land (about 10 million rai or 1.6 million hectare) should be adopting sustainable agriculture practices (see figure 3.1). By 2026, about 7 percent of agricultural land (about 10 million rai or 1.6 million hectare) should be under organic agriculture, and 33 percent of agricultural land (about 109 million rai or 17.44 million hectare) should be under sustainable agriculture (see figure 3.1). Ultimately, by 2030, 30 percent of agricultural land (about 40 million rai or 6.4 million hectare) should be under organic agriculture, and with the remaining 70% of agricultural land (about 109 million rai or 17.44 million hectare) under sustainable agriculture (see figure 3.1).

While the Thai Parliamentary targets relate to all agricultural sectors, it is assumed that up to 80 percent of the area targeted for organic agriculture development will be used for organic rice production (as discussed below).

Part 6 of the report will assess the effectiveness of different policy instruments to achieve enhanced or ambitious changes in agricultural practices. The direct policy instruments aim to identify the impacts of direct policies that target to increase area of organic rice practice. This assessment will look through possible intervention measures that the government could adopt to promote the adoption of improved practices by farmers.

Figure 3.1 Targets set for sustainable and organic agriculture for all crops in Thailand, 2019



Source: Committee on Agriculture and Cooperatives https://bit.ly/2QOj46D.

Scenario 1: Business as usual

Assumes that the government's One Million Rai Organic rice programme is implemented in line with published targets, and participants targetted continue to practice organic rice farming in subsequent seasons. In this scenario, no new policy initiatives are implemented for further promotion of the organic sector after initial targets are met.

This scenario is put forward to provide a predicted baseline of organic rice development for comparison with alternate scenarios described below. The One Million Rai Organic Rice promotion programme of the Ministry of Agriculture and Cooperatives (MoAC) was set up in 2017 and was scheduled to run until 2019. It takes at least three years for a farmer practicing organic farming to qualify for certification, so the rate of increase of area under organic rice production generated through this programme will only be known after 2021.

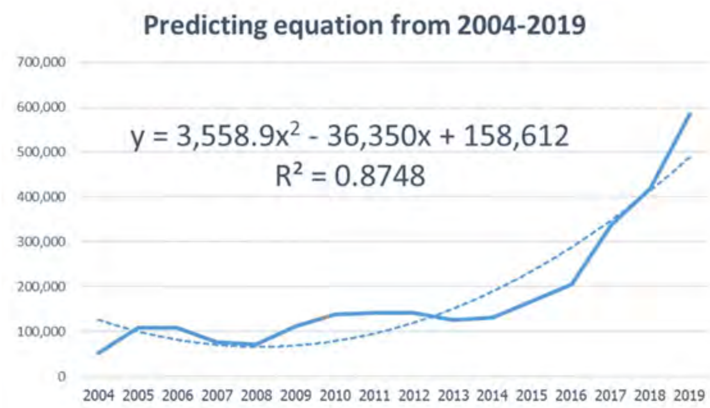
At present, according to available information[48], approximately 583,552 rai is being cultivated through organic methods and eligible for certification, and many more areas are in transition.

The business as usual scenario therefore takes into account the expansion of the area under organic rice that is currently taking place through the implementation of the government's One million rai Organic Rice promotion program, which started in 2017. It makes the assumption that the One Million Rai Organic Rice programme is fully implemented and that all farmer households participating will continue to practice organic rice farming successfully on their land and ultimately gain "Organic Thailand" or other recognized certification. In reality, it can be expected that there will be some fluctuation in the numbers of farmers who take part and stay with the programme, but it is not deemed feasible to assess the expected rate of adoption based on current data available. The business as usual scenario assumes that the area of organic rice production would remain steady after 2025.

According to the available data on the area producing organic rice from 2004 to 2019, the quadratic time trend of organic rice area was estimated as an equation of $y = 3{,}558.9x^2 – 36{,}350x + 158{,}612$ ($R^2 = 0.8748$), Y is the organic rice area and x is number of years as showed in the figure 3.2. Next, the organic area in the year after 2019 were predicted by this equation.

Figure 3.2 The predicting equation of increasing rate for organic rice area before 1 million rai policy period

[48] Statistics of the area under organic rice have been published on the Research Institute of Organic Agriculture (FiBL) website in 2018. This has been supplemented with an update of additional organic area from rice department in 2019 Source: http://www.ricethailand.go.th/ricemarket/images/PDF/29-5-63/organic62_T3.pdf



On this basis, it is assumed that the areas producing certified organic rice will reach just over one million rai (173,027 hectares) in 2025. That is, the BAU scenario assumes that the targets are met by 2025. In the BAU scenario, it is assumed that this area is maintained until at least the year 2035. BAU does not assume that new policies are developed, and also does not assume that a significant number of farmers revert on balance to conventional agriculture. Under the business-as-usual scenario, therefore, it will be assumed that the area for organic rice production would increase to 1.57% of the current land area for growing rice nationwide. It should be noted that land pattern change from other crops to rice will be not considered in this study.

It is expected that under this BAU scenario, the organic rice production area in the northeast would be:

a. By 2019: 583,552 rai (93,368 hectares), 1.59% of total rice area in the northeast
b. By 2025: 1,081,420 rai (173,027 hectares), 2.96% of total rice area in the northeast
c. By 2030: 1,081,420 rai (173,027 hectares), 2.96% of total rice area in the northeast
d. By 2035: 1,081,420 rai (173,027 hectares), 2.96% of total rice area in the northeast

Scenario 2: One Million Rai Organic Rice promotion continued

This scenario assumes that the One Million Rai Organic rice program is continuously implemented after 2020 to increase the adoption of organic agriculture by Thai rice farmers expanding the area under organic production by a million rai every five years.

This scenario assumes that the organic rice production program target as per the Ministry of Agriculture and Cooperatives (MoAC) is implemented in all provinces across the country to encourage farmer participants to increase the area under organic cultivation practices to at least one million rai by 2019. For the purposes of this analysis, this scenario assumes that one million rai of organic rice will be certified under the Organic Thailand scheme by 2021. In addition, this scenario also assumes that policy initiatives to support the adoption of organic farming continue to be developed between 2020 and 2035 to continue to expand the adoption of organic agriculture by Thai rice farmers at around one million rai for every five years. This scenario assumes that the area for organic rice production would increase to 5.8% of the current land area for growing rice nationwide. It should be noted that land pattern change from other crops to rice will be not considered in this study.

Based on the assumption that the area under organic rice will be located in the Northeast of Thailand, it is expected that under this scenario, the organic rice production area in the northeast would be:

a. By 2019: 583,552 rai (93,368 hectares), 1.59% of total rice area in the northeast
b. By 2025: 2,000,000 rai (320,000 hectares), 5.47% of total rice area in the northeast
c. By 2030: 3,000,000 rai (480,000 hectares), 8.20% of total rice area in the northeast
d. By 2035: 4,000,000 rai (640,000 hectares), 11.93% of total rice area in the northeast

Scenario 3: Enhanced organic rice promotion

This scenario assumes that the One Million Rai Organic rice and other intervention programmes are continuously implemented after 2020 to add additional 1 million rai of organic rice every year from the adoption of organic agriculture by Thai rice farmers

The scenario also assumes that policy initiatives to support the adoption of organic farming continue to be developed by the Ministry of Agriculture and Cooperatives, in collaboration with other ministries including the Ministry of Natural Resources and Environment, the Ministry of

Public Health, the Ministry of Commerce between 2020 and 2035 to continue to expand the adoption of organic agriculture by Thai rice farmers at the one million rai per year as growth rate. This assumption is based on the aim of the MoAC to enhance the promotion of organic rice cultivation in the Northeastern region. Potential initiatives that might be adopted to promote the continued expansion of the organic rice sector beyond 2021 are explored in Part 6 of this report.

Based on the assumption that the area under organic rice will be located in the Northeast of Thailand, it is expected that under this scenario, the organic rice production area in the northeast would be:

a. By 2019: 583,552 rai (93,368 hectares), 1.59% of total rice area in the northeast
b. By 2025: 5,000,000 rai (800,000 hectares), 13.67% of total rice area in the northeast
c. By 2030: 10,000,000 rai (1,600,000 hectares), 27.33% of total rice area in the northeast
d. By 2035: 15,000,000 rai (2,400,000 hectares), 41.00% of total rice area in the northeast

Scenario 4: Transformational change towards sustainability

Assumes that demand grows significantly for organically produced rice, and that powerful policy initiatives are developed to meet the ambitious targets of the Thai Parliament for the development of organic and sustainable agriculture by 2030.

This scenario assumes that policy initiatives are developed in 2020 to meet the ambitious Thai Parliamentary targets for 100 percent of Thailand's agricultural land (149 million rai or 23 million hectares) to be cultivated using organic or sustainable agricultural practices by 2030, and in the light of increasing public attention and concern for promoting sustainable agriculture. According to the Parliamentary targets, organic farming practices should be applied nationwide in an area of 40 million rai by 2030, equivalent to 30% of Thailand's farmland.

For the purposes of this analysis, it is assumed that up to 80 percent of the area targeted for organic agriculture development would produce organic rice, such that 32 million rai of land in Thailand would be dedicated to organic rice production by 2030. In order to meet these targets, the area for organic rice production would need to grow significantly, at a rate of 43.9 percent annually. It should be noted that land pattern change from other crops to rice will be not considered in this study.

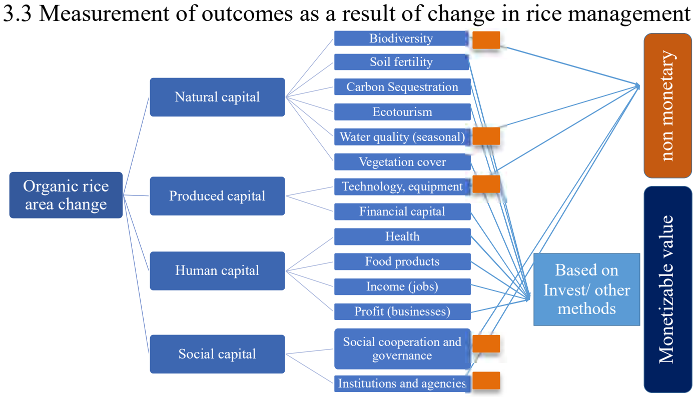
Based on the assumption that these organic rice areas will be located in the Northeast of Thailand, it is expected that under this scenario, the organic rice production area in the northeast would be:

a. By 2019: 583,552 rai (93,368 hectares), 1.59% of total rice area in the northeast
b. By 2025: 5,184,064 rai (829,450 hectares), 14.17% of total rice area in the northeast
c. By 2030: 32,000,000 rai (5,120,000 hectares), 87.46% of total rice area in the northeast
d. By 2035: 32,000,000 rai (5,120,000 hectares), 87.46% of total rice area in the northeast

For each of the scenarios above, the research team will apply the TEEBAgriFood Evaluation process to examine the likely change in ecosystem service provision at each of these timeframes, comparing between organic and conventional rice production systems (scenarios 1, 2, 3, and 4).

Changes in cultivation areas between conventional and organic rice under each scenario situation will be then used to identify the impact of changes in measurement outcomes presented in figure 3.3

Figure 3.3 Measurement of outcomes as a result of change in rice management practices



The area changes under each scenario will be linked to measurable changes in various capital stocks and flows related to four dimensions: natural capital, produced capital, human capital and social capital. Changes in the stocks of capitals are 'outcomes' which will have impacts on wellbeing. Outcomes related to **natural capital** stocks that are covered in this study will include changes to soil fertility, quality of habitat and biodiversity, ecosystem services, GHG emissions, and air pollution. Outcomes related to changes in **produced capital** will include changes in yield and income from rice production as well as access to relevant production infrastructure such as farm machinery and community rice mills. Outcomes in terms of changes in **human capital** will relate to changes in health impact related to pesticide and air pollution on both farmers and consumers . The research team is aware that some outcomes may not be directly able to be linked to changes in the cultivation area between conventional and organic rice practice, in particular outcomes in **social capital** dimension, including social cooperation, trust, and empowerment, for example.

Part 6 of the report will assess the effectiveness of different policy instruments to achieve enhanced or ambitious changes in agricultural practices. The direct policy instruments aim to identify the impacts of direct policies that target to increase area of organic rice practice. This assessment will look through possible intervention measures that the government could adopt to promote the adoption of improved practices by farmers.

Part 4: Research methodology and results

This part of the report presents the methodologies and results of various analyses to access effects of land-use change due to changes of conventional and organic rice areas based on each scenario on environment, health of people, rice production, and socioeconomics of farmers.

The first section of this chapter presents land-use change modeling that highlights how and where the conventional rice areas are converted to organic rice for each scenario. The results from land-use change modeling will be then 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 (e.g., watershed level) 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.

The second section presents the impacts of land-use changes on biodiversity, measured by the diversity of insects in rice systems in the Northeast of Thailand. The biodiversity index between conventional and organic rice practices are compared and spatially analyzed based on land-use change of each scenario. Greenhouse gases emissions due to land-use changes in each scenario are analyzed in third section, followed by projections of rice yield in each scenario in the fourth section. The fifth section of this report focuses on the effects of land-use change in each scenario on people health, consisted with the effect of air pollution, PM2.5 on people health and the effect of pesticides on farmers' health. The final section provides analyses of socio-economic data from rice farming households, based primarily on a household survey.

In the next part of the report (Part 5) the socio-economic data is integrated with the biophysical data to quantify the effects of different rice production practices (for example, the change in natural capital such as GHG emission, or the change in rice yield, and cost of production). The policy scenario analysis results are also elaborated in each section.

1. Land-use change modeling

Predictive land use (LU) scenario modeling integrates existing and new biophysical and valuation data (as presented in the following sections) to provide an assessment of the changes in ecosystem service provisioning as a result of the expansion of the area under organic rice.

In the first step of LU modeling, a land-use change model has been processed using IDRISI-TerrSet[49] and Land Change Modeller (LCM) for assessment and projection of land cover change. This exercise is complementary to the household survey aimed at further understanding socio-economic and cultural factors for a switch from conventional to organic, see Part 4, section 6 of this report.

In LCM, the changes of land-use (LU) start with two land use maps on a regional scale to analyze the land cover changes and patterns which refer to two different years (T_1 and T_2). The first set of land use data relate to 2015 (T_1) and the second relate to 2019 (T_2) The processes of change are estimated and were used for model calibration.

The next step is to apply explanatory spatial variables and driver variables to create maps to identify where land use transition would potentially take place. The explanatory spatial variables are presented in Table 4.1. These include biophysical factors (i.e., slope, elevation, suitability), climate variables, and geographical criteria (i.e. population density, location of reservoirs, roads, and settlements). The locations of respondents' farm plots from the household survey are used to supplement data relating to the organic cultivation area. The spatial location of individual's rice paddy was recorded during the household survey using the Google Maps application. The information was used to illustrate the distribution of organic rice paddy linking to the future LU prediction.

Table 4.1 Summary data used for land-use change analysis.

Names	**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 (2015 and 2019)	Land Development Department, MoAC
Suitability	Land suitability for rice cultivation.	Land Development Department, MoAC
Organic rice paddy	Locations of certified organic rice plots in 2015 and 2019	Rice Department, MoAC
Road	Thailand road network, including all types	GISTDA Thailand
Elevation	Digital Elevation Model > SRTM 30m. Elevation, aspect	Digital Chart of the World

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

Names	Description	Sources
Slope	A slope in degree calculated from Digital Elevation Model (DEM)	Author calculation
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[50]
Distance to urban area	Euclidean distance from urban LU type based on Land Development Department definitions of U1, U2, and U3 land use classes	GISTDA Thailand

Figure 4.1 illustrates the method for predicting land use change. The level of association of explanatory variables is tested whether it represents the phenomena process as driver factors in land use transition (Cramer's V test). These values were processed through a knowledge-based approach to machine learning. Using a Multi-layer perceptron (a type of artificial neural network), the relationship between the land use variables and drivers (driving factors) are modelled. A random selection of half of the set of data pixels is then used for predicting changes in land use classes based on changes in input variables and drivers. The other half of the set of pixels are used for validation of modelled predictions. . This information is used to predict the change in land use classes in the next step.

Land use is classified according to the definitions set out by the Land Development Department, specifically level 2 and level 3 classifications, which relate to, for example, paddy field, field crop, mixed field crop, sugarcane, others. Supplementary data from the Rice Department, MoAC was used to identify where land was used to grow organic rice in 2015 (T1) and 2019 (T2) and this was used to predict future change to this type of land use.

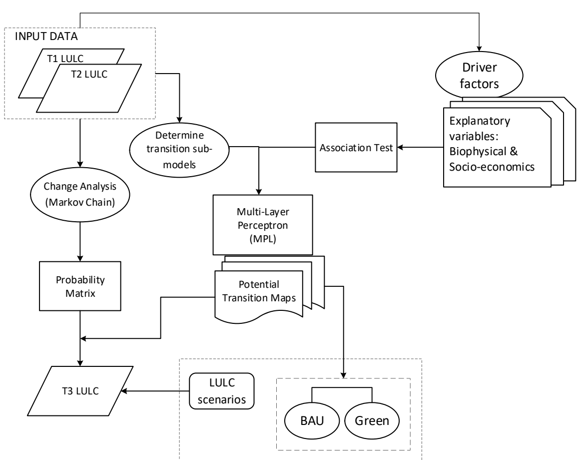
To predict LU change, the probability of change is determined by projecting historic changes into the future. Based on a Markov Chain analysis, the probability estimates for each pixel on the land use map are assigned. Maps are then generated showing transition potential, indicating whether a pixel is likely to transform to another LU or persist with the current land use. The transition must be modeled before change prediction can be undertaken. In this study, the transition potential map is focused on the transition from conventional rice to organic rice because it

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

corresponds to the current government policies. The zoning is informed by the Agri-Map project[51], developed by the Land Development Department (LDD) of the Ministry of Agriculture and Cooperatives. This project has assessed and identified areas which are suitable for rice growing as described in Part 2 of this report. For the transition potential map used in this study, only land that is deemed suitable for rice production according to the AgriMap is conserved to have transition potential to organic rice[52]. According to LDD, most of the land in the Northeast region is marginal suitable land for growing rice. Thus, within the model developed, the areas that have the potential to convert to organic rice are only those where conventional rice is already being grown, and only where rice is deemed to be a suitable crop according to AgriMap.

In the next step, once the transition probability is modelled, this model is run over a certain period of years to determine how much land would be allocated to a particular class of land use over time. The final step is for the change predictions to be presented in maps according to different scenarios over a selected future date (T3).

Figure 4.1 Land Change Modeller method to predict land-use change



The scenarios for the simulated organic rice expansion correspond to the increasing organic cultivation area. The analysis simulates land use under four different scenarios as described in the previous section, namely 1) Business as Usual (BAU) scenario, 2) One million rai organic rice

[51] Land Development Department (LDD), MOAC
[52] Department of Agricultural Extension (DoAE), MOAC

promotion continued, 3) Enhanced organic rice promotion, and 4) Transformational change towards sustainability. Each scenario is assessed through projections in the years 2025, 2030, and 2035, respectively. The projection analysis runs every five-year time window and ends in 2035 because the government action in rice production can reflect Thailand's agricultural policies and development strategies under the Twenty Year National Strategy. According to our assumptions, the LU of rice area is control where rice is suitable to cultivate. There is no transformation of rice area and changes after 2035.

The spatial analysis of land-use change is further linked to biophysical modeling as changes in land-use affect the provision of terrestrial ecosystem services. The predicted land-use changes from the above spatial analysis are used later in this study as input for further analysis in the natural capital stock and assessing the value of ecosystem services.

The analysis of LU change comprises three parts: 1). data pre-processing, 2) land-use change analysis, and 3) predicting future organic rice expansion. The relevant explanatory driver variables (Table 4.1) are prepared and converted into the appropriate format for further analysis in the pre-processing stage. Two LU layers, using data from the LDD, were modified to integrate the organic rice paddy field data as a new category of LU for both years 2015 and 2019. LU classes were reclassified into ten classes (Table 4.2) and further used to determine the ecosystem services changes.

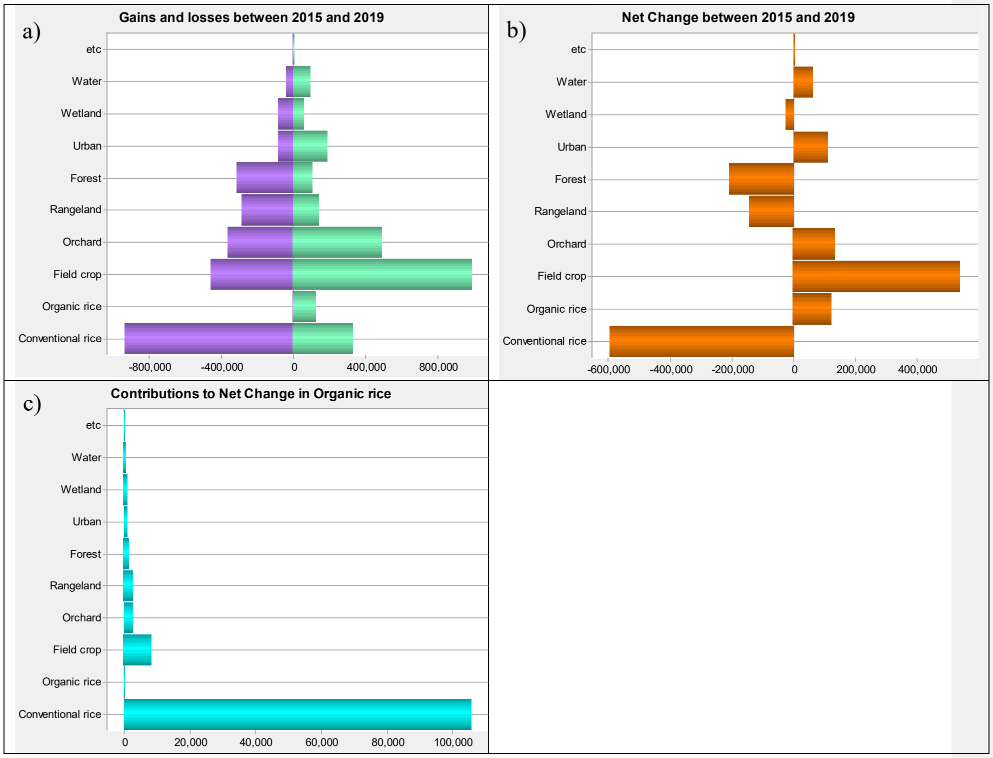
Table 4.2 Land-Use reclassification

LU_LDD Class	Description
A1	Conventional paddy field
A2	Field crop
A3	Perennial crop
A4	Orchard
A5	Horticulture
A6	Shifting cultivation
A7	Pasture and farm house
A8	A quatic plant
A9	A quacultural land
A10	Integrated farm Diversified farm
F1	Evergreen forest
F2	Deciduous forest
F3	Mangrove forest
F4	Swamp forest
F5	Forest plantation
M1	Rangeland
M2	Marsh and Swamp
M3	Mine, Pit
M4	Other miscellaneous land
M5	Salt flat
M6	Beach
M7	Garbage dump
U1	City, Town, Commercial
U2	Village
U3	Institutional land
U4	Communication and utility
U5	Industrial land
U6	Other built-up land
U7	Golf course
W1	Natural water body
W2	Artificial water body

pixel value	New class description
1	Conventional rice
2	Organic rice
3	Field crop
4	Tree plantation Orchard
5	Rangeland grassland
6	Forest
7	Urban
8	Wetland
9	Water
10	Others

The second step in LU change modelling is the LU change analysis. The change analysis was performed by analysing the differences between two LU maps, 2015 and 2019. The change analysis present in three aspects (gains or losses of LU, net change by category, and contributions to the net change in organic rice). Panel a), the LU change of each class was calculated as a gain or a loss in area. The unit of analysis is presented as an aerial unit, hectare. The first graph illustrates the gain and losses between 2015 and 2019 (Figure 4.2a). The purple bar represents a loss of land category, and the green bar indicates a gain in the area. From this graph, it can be seen that the area of conventional rice decrease significantly, followed by the area of field crop, orchard, forest land, and rangeland, respectively. The organic rice area seems to have a minimal increase relative to conventional rice and other categories of LU. There were few losses in the organic area. For the most part, farmers did not abandon organic land use during the control period between 2015-2019. To certified organic rice production in Thailand, the procedure takes three consecutive years of transformation (Tier 1 to Tier3). It is potentially that the losses area of organic rice (2208 ha) are the uncertified organic rice and switch back to conventional rice or other type of agricultural land.

Figure 4.2 Land Use Change analysis in the Northeast of Thailand between 2015 and 2019



Data source: Land Development Department, MOAC Thailand. Units: ha

Figure 4.2.b shows the net change in each category. In relation to organic land use, 125,937 ha were gained, while 2,208 ha were lost, resulting in a net change of 123,729 ha. The net change of orchard area is similarly in quantity of net change to organic rice area while field crop has the highest value of net change. Figure 4.2.c illustrates which other land use categories contributed to the organic rice category. In other words, it shows which type of land use the organic rice replaced. Mostly organic rice replaced conventionally grown rice. Organic rice was also grown on land that was previously used for field crops, rangelands, and wetlands. In regard to wetland conversion to rice fields, according to key informants, this relates to areas of land which are seasonal wetlands - areas that flood each year during the rainy season. Once the flood waters recede during the dry season, small farmers use these areas to grow rice. Once the rains return, farming ceases in these areas, such that the areas continue to function as natural wetlands during this part of the year. For

the conversion of forest to organic rice, the net change is approximately 1,676 ha, or approximately less than 10% of total forest land that has been converted from forest to organic rice (Table 4.3). It is possible that such conversion to organic rice is from low quality forestland that has been legally reclassified for agricultural land use (Praweenwongwuthi et al., 2017).

The data used to analyze in Table 4.3 is based on observed changes between 2015 and 2019. Note that the future potential land use changes to organic will only be predicted by the model in areas that are currently designated as suitable for conventional rice production.

Table 4.3 Organic rice area expansion in the NE from 2015 to 2019

Land-use class	2015 (Hectare)	2019 (Hectare)	Change rate (%)		Change area (Hectare)			Contribution to net change in Organic rice farming area	
			Loss(-)	Gain(+)	Loss (-)	Gain (+)	Net change	Hectare	%
Conventional rice	7,015,866	6,421,835	-13.29	5.26	- 932,111	338,080	-594,031	105,553	1.50
Organic rice	2,208	125,937	-100	100	- 2,208	125,937	123,729	-	-
Field crop	2,661,035	3,200,115	-17.04	31.02	- 453,508	992,588	539,080	8,351	0.31
Orchard	1,705,639	1,840,651	-21.04	26.84	- 358,935	493,947	135,012	2,477	0.15
Rangeland	606,123	462,421	-47.24	30.84	- 286,321	142,619	-143,702	2,757	0.45
Forest	2,902,773	2,694,941	-10.85	3.97	- 314,844	107,012	-207,832	1,676	0.06
Urban	995,230	1,105,157	-8.14	17.28	- 81,030	190,957	109,927	982	0.1
Wetland	230,225	205,916	-35.77	28.18	- 82,340	58,031	- 24,309	1,171	0.51
Water	580,504	641,166	-5.83	14.74	- 33,858	94,521	60,663	763	0.13
Other	1,035	2,499	-74.88	89.59	- 775	2,239	1,463	-	0.03

Source of data: LDD, MOAC

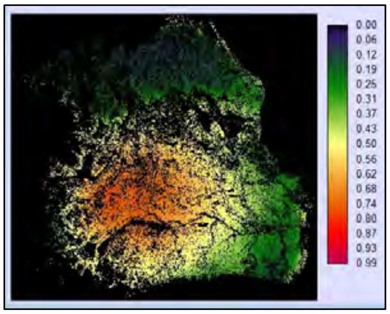
1.1 Assessment of transition potential modeling

The next step of LU change analysis was to work out the potential for transition to organic rice expansion. The transition potential model was based on the result from the landuse change analysis between the two periods (2015 and 2019). In this model, five explanatory variables were added, including climate data and distance to urban (see Table 4.1). Three climate driver variables were the minimum, the maximum, and the average of temperature. The monthly precipitation is the sum to represent the annual value applied in this study. The climate data were derived from the Representative Concentration Pathways (RCP) adopted by the IPCC, specifically, emissions scenario RCP 4.5. It was updated from previous models to incorporate the historical emission and landcover information. RCP4.5 simulates future emission with the potential future economic activity. Climate predictions were developed for the period 2010-2035 to cover the entire Northeast region using the (EC-Earth) model[53]. RCP 4.5 is applicable in projecting landuse change analysis (Pechanec et al., 2018). The distance to urban areas variable is included as an input to model population growth effects. This is measured in Euclidean distance to urban areas. Urban development substantially impacts LU change prediction, especially in agricultural land-use literature (Jiang et al., 2013). The other two driver variables relate to changes in land use, specifically land use change from conventional rice to organic rice and land use change from all land use classifications to organic rice.

All driver variables were used to construct the training and learning process (Multi-Layer Perceptron method) by randomly selecting the sample pixels from two LU data points (a total of 10,000 pixels per class). The procedure was repeated through 10,000 iterations. As a result, the potential transition maps were produced. Figure 4.3, illustrates the result of the modelling of the transition potential area (from conventional rice to organic rice) of the entire NE region. The transition potential map scale ranges from 0 to 1, with color indicating the potential of transition. The areas shaded in reds (with a high value close to 1) have a high potential to transition to organic rice conversion, while the areas in blue and purple shades (with a low value close to 0) has a low potential to transition to organic rice conversion. It can be seen that the lower-central region of NE has a high transition potential of conventional to organic conversion. This correlates with the Agri-Map project, which indicates that this area is a suitable location for rice cultivation at a moderate to a high level.

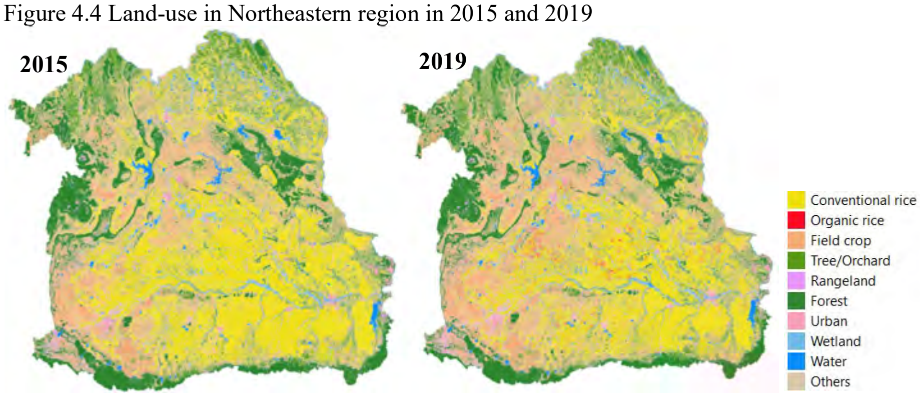
Figure 4.3 Map of Northeastern region indicating potential areas of conventional rice conversion to organic rice farming

[53]The Coupled Model Intercomparison Project phase 6 (CMIP6). The downscaling and calibration was done with global climate models and shared socio-economic pathway. Data is in monthly 30m resolution.



The last step is predicting future organic rice expansion. This is carried out using a change demand model. In this model, the forecast of future organic rice expansion is determined using a a transition probabilities matrix, using the Markov Chain process. The difference (change) between the LU maps in 2015 and 2019 (see Figure 4.4) and the future dates specified for projection (2025, 2030, and 2035) are used to create the transition probabilities matrix. The matrix records the probability that a particular land-use category will change to any other category. The area targeted for organic cultivation as outlined in each scenario was used as criterion in the prediction model.

Figure 4.4 Land-use in Northeastern region in 2015 and 2019



1.2 Results of land use change modelling in four scenarios

Figures 4.5-4.8 show a series of scenario predictions for organic rice area expansion. The first scenario (BAU) assumes that after the One Million Rai Organic Rice program is completed, the area where organic farming is practiced neither expands nor contracts until at least the year

2035. The model results show that the expansion of organic fields is predicted to begin around built-up and developed areas such as near roads and residential zones. The main areas of organic rice expansion are located in Khon Kaen, Nakorn Ratchasima, and Buriram provinces (Figure 4.5). The organic area is projected to increase by approximately 85 percent from 2019 to 2025. After 2025, the organic rice area is assumed to remain stable at 233,182 hectares.

The second scenario assumes that the One Million Rai Organic rice program is continuously renewed after 2020 to promote the adoption of organic agriculture by Thai rice farmers, expanding the area under organic production by a million rai every five years. The growth rate of organic rice expansion is high until 2025, similar to the BAU projection in Khon Kaen, Nakorn Ratchasima, and Buriram provinces. During 2026-2030, the organic rice area in these provinces expands, and organic practices extend into Surin and Mahasarakham province. The organic rice area continues to grow, but at a decreasing rate during 2031- 2035. During this period, the new growth is projected in the area near Roi Et province. Figure 4.6 shows the predicted areas of expansion from 2025 to 2035.

The third scenario assumes enhanced promotion of organic production over and above the continuation of the One Million Rai programme. The organic rice area is expected to grow in a pattern of expansion similar to Scenario 2, but with a more intensive rate of growth (Figure 4.7). By 2035, organic rice is beginning to be produced in a few isolated areas of the Northern part of the NE (including Nakorn Phanom and Mukdaharn province). Yasothorn and Sisaket provinces gradually gain organic rice cultivation area, while in the early adopter provinces almost 90% of the rice cultivation area is predicted to have adopted organic practices by 2035.

The last scenario represents the transformational change towards sustainability. This is based on a national target of 40 million rai of agricultural land being converted to organic practices by 2030. For this scenario, it is assumed that up to 80 percent of the national area targeted for organic agriculture development would be dedicated to produce organic rice, such that 32 million rai of land in Thailand is assumed to be dedicated to organic rice production by 2030. This scenario also assumes that all of this 32 million rai of land dedicated to organic rice would be located in the Northeast of Thailand. On this basis, it is not surprising that that almost the entire area growing rice conventionally today in the NE would have converted to producing organic rice in 2030 and 2035. A few provinces, namely Loei and NongKhai, are predicted to be late converters.

As a result of four scenarios, the projected spatial development of organic rice projection can be seen to progress from the lower central part of the region, specifically Khon Kaen, Nakorn Ratchasima, and Buriram provinces, moving through to the South and East, and eventually covering the Northern provinces of the region.

Figure 4.5 Organic rice expansion in BAU scenario (Scenario1)

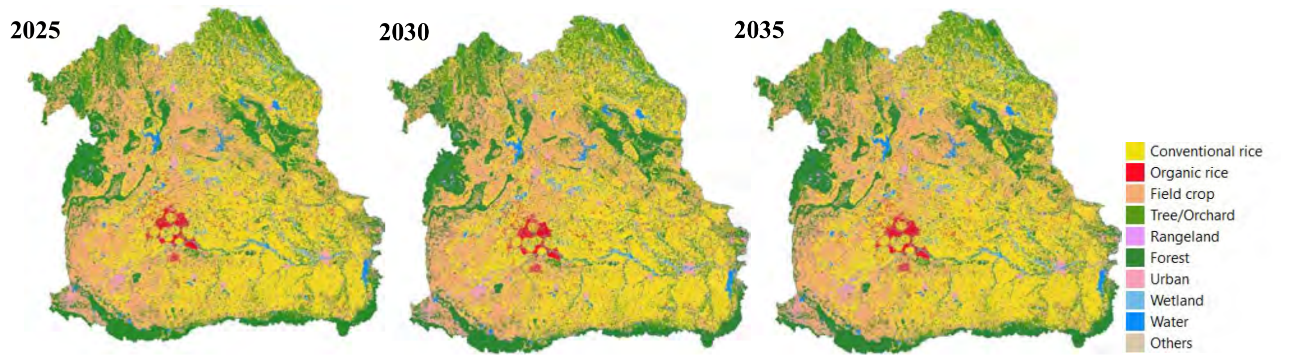


Figure 4.6 Organic rice expansion under the One Million Rai Organic Rice promotion continued (Scenario2)

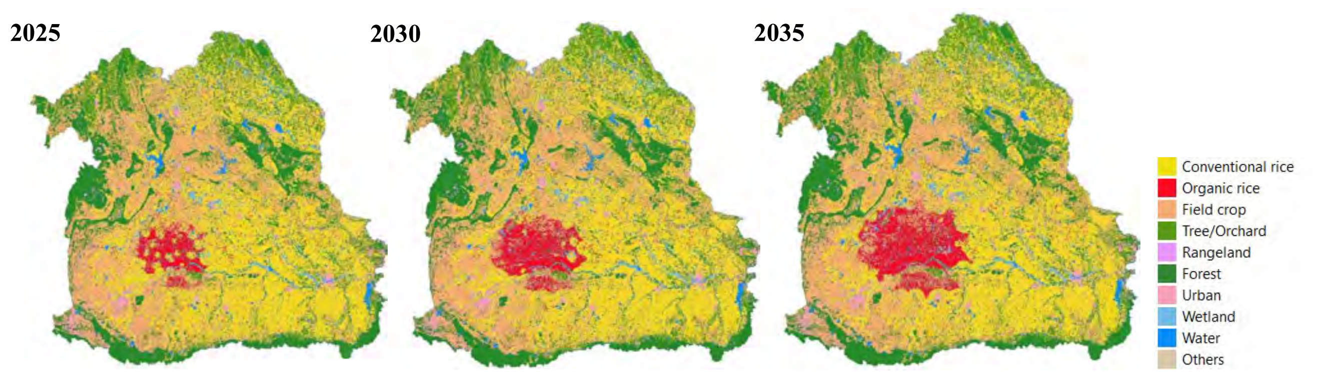


Figure 4.7 Organic rice expansion under the enhanced organic rice promotion (Scenario3)

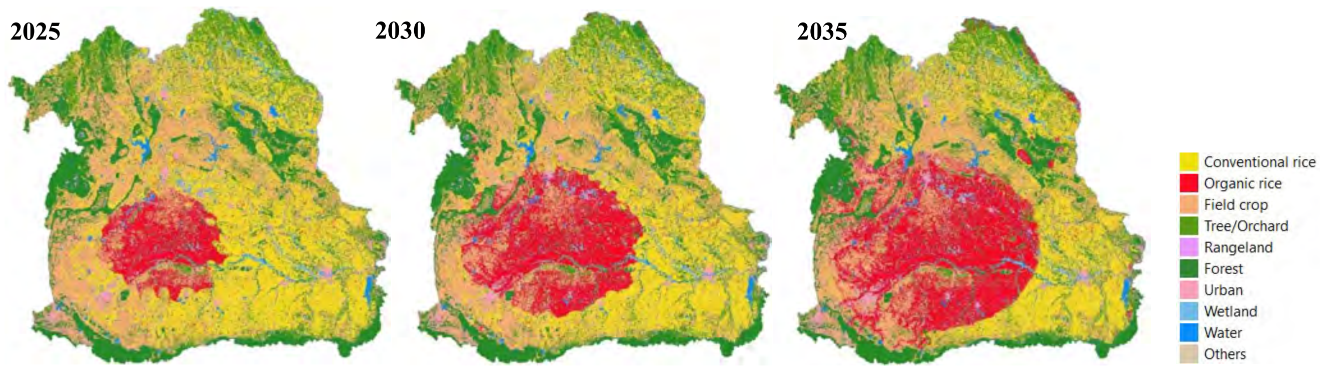
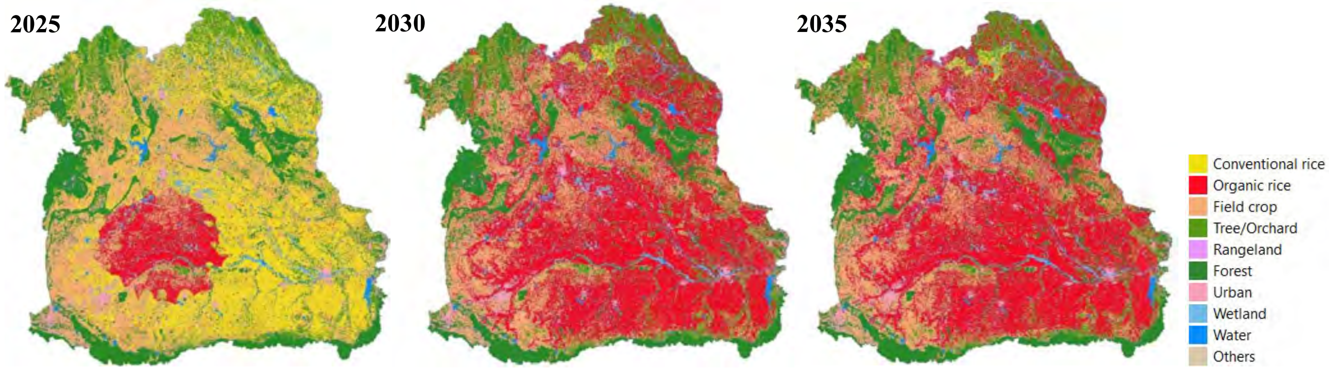


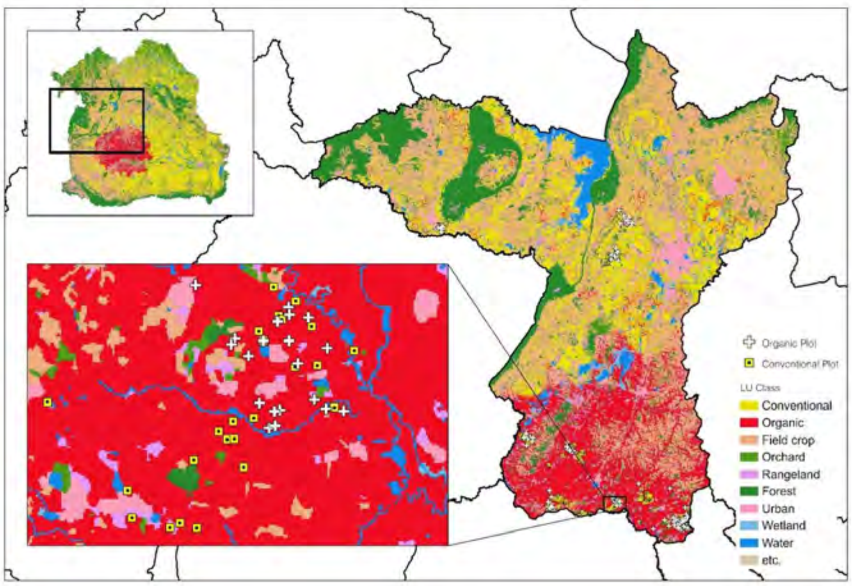
Figure 4.8 Organic rice expansion under the transformational change towards sustainability (Scenario4)


2025
2030
2035
Conventional rice
Organic rice
Field crop
Tree/Orchard
Rangeland
Forest
Urban
Wetland
Water
Others

1.3 Linking Household Survey and LU Prediction of Organic Rice Paddy Fields

In this section, the household survey data complement the results of land use change to illustrate farmers' responses in spatial distribution. The sample of representative farmers in the NE accounts for both groups of farmers, organic and conventional rice farmers registered in the official farmers directory and the certified organic rice farmers (DoAE). The approximate sample size is calculated using a stratified random sampling scheme giving the approximate 800 farmer samples in total. This sample size is reliable for farmer population of the Northeast region at 95% confidence level with the accuracy of five percentage points. The household surveys were carried out across the northern part (Khon Kaen province) and the southern part (Surin and Buriram province) of Northeast Thailand. Further details of this survey are provided in Part 4 section 6 below. The geographic stratum is used to calculate the size of the sample in each province where the sample is proportional allocation. A summary of household characteristics and the potential factors affecting farmers' decisions in the socioeconomics is presented towards the end of this section.The first part is a snapshot of organic rice prediction with the household survey. The locations of paddy fields of the participants in the household survey were recorded to examine the spatial distribution of the survey participants. These are presented in Figure 4.9 below, with white crosses to indicate organic fields, and yellow squares for conventional fields. Eventually, it is predicted that the conventional rice fields would convert to organic rice because they are located in predicted organic rice areas.

Figure 4.9 Location of organic and conventional rice fields of household survey participants, plotted against a background of the transition potential map



The future changes in land use towards organic rice production predicted by our model are based on an analysis of a limited set of socio-economic factors that affect land-use decisions (as described in the previous section). However, we posed a hypothetical question asking whether they would like to continue growing rice in the same piece of land for the next ten years. Three optional responses were allowed; yes, no, and not sure.

Figure 4.10 shows the spatial distribution of answers to the hypothetical question for farmers who have adopted organic practice (left panel) and conventional practice (right panel) to the hypothetical question. Most farmers responded that they intend to continue to use the land for agricultural use, rice cultivation, in the next ten years, at the least their children generation. The background layer is the land use projection in 2030 (under the BAU Scenario) which matches the ten-year outlook implied in the question, where the red and yellow pixels indicate the predicted organic rice and conventional rice fields, respectively. Most organic rice farmers responded that they would continue to use the land for rice in the next ten years. Fewer conventional rice farmers responded that they would continue to use the land for rice. There are very few observations found that organic rice farmers refuse to continue agricultural land use. Farmers who refuse to continue using the land as it is today are often found located on conventional rice fields (The pink dots are overlaid on the yellow pixels).

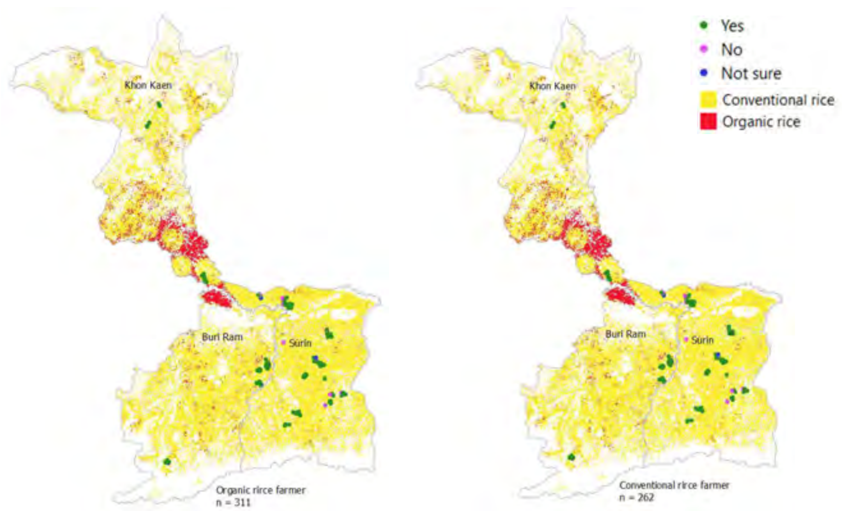


Figure 4.10 Spatial distribution of land use decision from the household survey with the BAU projection in 2030, in three provinces. The left hand side map shows organic farms whilst the right hand side map shows conventional farms.

According to previous studies from Thailand, there are several other potential factors that influence changing from conventional rice to organic rice production (Chinwarasopak, 2015; Markandya & Setboonsarng, 2015). The psychological factors have a strong influence on rice farmers in the NE. The organic rice farmers have a positive attitude toward organic farming practice such as low cost of production techniques. Organic practice also offers an alternative solution for problem facing conventional rice production such as soil degradation (Pornpratansombat et al., 2011). The same study also found that perception related to human and animal health risk influences the adoption of organic rice farming. The influence of attitude factors that would affect farmers' decision to switch from conventional rice practice to organic rice practice are further analyzed in Part 6 of this report on the economic valuation with socioeconomic data.

1.4 Discussion and conclusion on scenario modelling and mapping.

In conclusion, the land-use analysis aims to present a projection of the organic rice expansion according to the four scenarios of organic rice policy. The rice policies rely on Thailand' agricultural policies and the national development strategies. The framework of the analysis intensively is controlled by the biophysical variables and socioeconomic variables. In particular, we focus on the spatial distribution of the transformation of areas with conventional rice to organic rice and other land uses across scenarios. As a result, we found that a majority of future land-use converted to the organic rice area is the current location of the conventional rice paddy fields. Many provinces with a large proportion of conventional rice area tend to be the areas that we found as the early conversion of organic rice paddy fields. The overall pattern of organic rice expansion starting from the central region of the NE plains and spreading initially toward the southwest region. The subsequent results show that the most land conversion resulted from the field crop and rangeland, where farmers often grow cassava, rubber, and sugar cane. For the NE Thailand setting, this pattern of land-use change is fairly typical and has been found in Praweenwongwuthi et al (2017). The authors also found that government regulation on agricultural land use is a crucial driver of land use conversion. In Nakhon Phanom province, for example, once the government reclassified the degraded forestland for agricultural uses, several areas were converted to paddy fields.

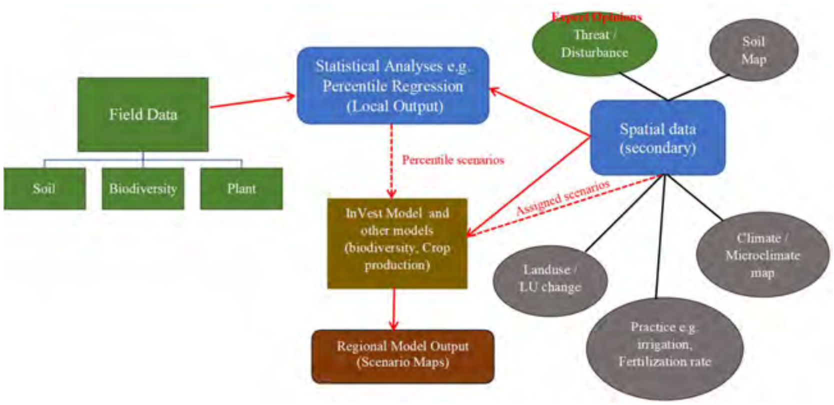
2. Communities, Biodiversity, and Ecosystem Services Modelling

The section sets out how biophysical modelling was carried out. The biophysical models were used to assess changes in ecosystem service provisioning and changes in capital stocks from organic versus conventional practices, based on the land-use change modeling outcomes under different policy intervention options. The changes in ecosystem services are described quantitatively and aggregated across the study region. In each of the four policy scenarios, the change in ecosystem services was determined, based on the land-use change modeling outputs, localized agronomic data and analysis, supplemented by secondary data on outcomes of different rice practices (agronomic and ecological outcomes at landscape level).

Rice fields are considered transient wetlands ecosystem characterized by rapid changes based on water regime and practices. In rice field ecosystems, insects are in the intermediate position in the food chain in a diverse environment mostly composed of herbivores, then predators, pollinators, and parasitoids. The biodiversity of rice field ecosystem is related with multiple functions that benefits yield and welfare e.g. food, pollination of native plants, resistance to diseases and pest due to pest control (Way et al. 1994; Cardinale et al. 2003), improving yield and reducing the use of insecticide (Feder et al. 2004). The goal of sustainably maintaining ecosystem services, such as pollination, and biological control is to maintain or promote biological diversity. The differences between organic and conventional rice farming practices , are the changes in physical and chemical composition of ecosystems, which cause difference in biodiversity, which is defined as the number and variety of species or taxa present in the rice field community. These results in the different services from ecological systems which affects the cost-benefit of rice farming, e.g. pest management, the uses of fertilizers.

The research team collected the biodiversity and environmental related data in each of the rice cultivation practices assessed in the selected samples of rice fields from 24 study sites in Buriram and Surin province. The research team undertook a quantitative and qualitative analyses of the differences in biodiversity and environmental responses between two rice cultivation practices. Firstly, biophysical characteristics were quantified and estimated at the landscape extent of rice paddies under conventional or organic farming practices. The biodiversity of vertebrates and invertebrates, especially insects, in the study sites were described and species diversity analysed according to the methods described in the next section. The study followed the framework shown in figure 4.11, with the field data collected at the designated site, the chosen statistical methods were applied to quantify the correlation between biodiversity and site-specific covariates composed of climate, landuse, and other environmental data, with some supplementation from the secondary sources. Then, the correlation results were used to predict the biodiversity at the regional level and testing if the biodiversity have an influence on yield and cost of the rice field.

Figure 4.11 Modeling framework for regional biophysical output and relationship between practice, biodiversity, and ecosystem services.



A total of 24 study plots (12 organic rice paddies plots and 12 conventional rice paddies plots) were selected from four different study sites based on known certified organic rice farming of two provinces as shown in Table 4.4 with at least 3 repetitive data collection for each plot at different stages of rice farming depending on water regime e.g. dry and wet periods. The organic rice paddies were selected on the basis that they are farmed by members of the local organic farming groups and have achieved certification following the Organic Thailand or other recognized standards. The conventional rice paddies were selected from farmers who are not members of the local organic farming group. For the purposes of this analysis, the definition of 'conventional' farming is set as farms which do not follow any organic farming standard, and are not in the process of seeking organic status.

Table 4.4 Study sites for farm-level biophysical data collection in Surin and Buriram

Rice production practice	Study sites			
	Buriram province		Surin province	
	Swai So, Nai Mueang Sub-District, Mueang Buriram District	Thalung Lak Sub-District, Mueang Buriram District	Tamor Sub-District, Prasat District	Bu Rue Si Sub-District, Mueang Surin District
Organic	6 plots	2 plots	2 plots	2 plots
Conventional	6 plots	2 plots	2 plots	2 plots

Figure 4.12 Images of study sites showing study plot locations. Swai So (SW),Thalung Lak (TL),Tamor (TP), and Bu Rue Si (BS)

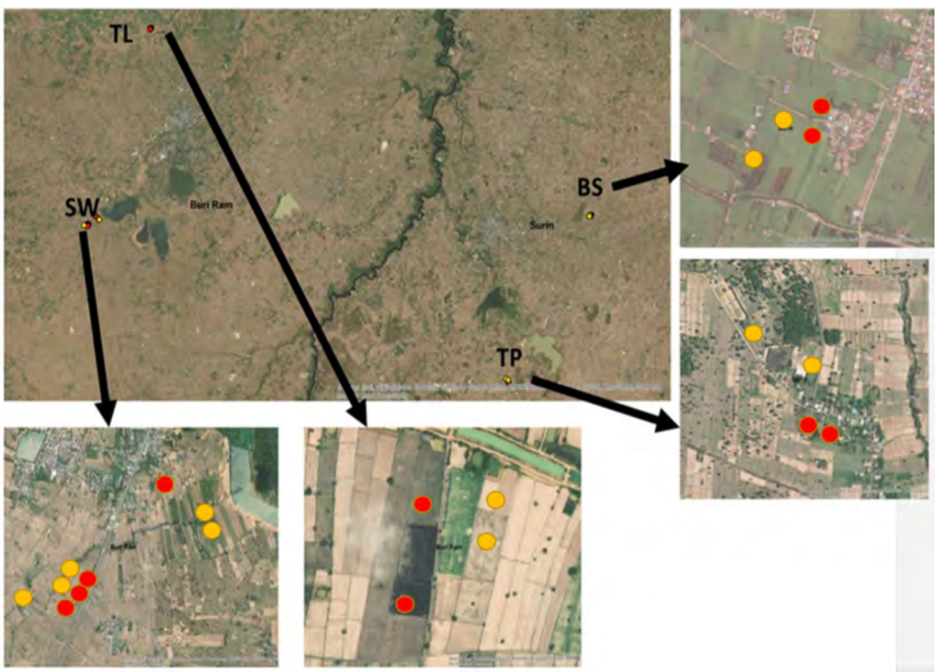


Figure 4.12 shows satellite images of plot clusters (total 24 plots) in four study sites representing different localities and rice farming practices (table 4.4) for collection of biophysical data in Buriram and Surin provinces. The yellow dots represent samples of rice farm with organic farming practice, while the red dots represent the location of conventional rice farming practice samples.

The anthropogenic impacts on biological diversity of target ecosystem as a result of conversion to organic cultivation will be assessed. Biodiversity will be modeled to estimate the capability of a given landscape (in this case the Northeastern region) to provide the conditions appropriate for the persistence of a given population species. The model requires current and scenario-based land cover map and data relating to rice farming practices that could be considered as benefitting or threatening the species in a human-dominated landscape. Proximity to threat sources and species pool will be also determined for natural habitats that are close to landcover or rice farming practices that are considered threatening to such habitats. The statistical model is also used to analyze the pattern of environmental effects on biodiversity.

2.1 Biodiversity

From the field study, the biodiversity from local sites were recorded across different farming practices in 24 locations in Surin and Buriram provinces. The biodiversity was quantified for each of 24 sites and composition of biological communities were analysed using ordination methods. The survey data of abundance and number of taxonomic groups were then quantified as indices. In this study, Shannon-Wiener biodiversity index and Simpson biodiversity index were used throughout the study and the similarity was quantified using Jaccard index. These biodiversity data were then inputted into the model to predict future changes at the regional scale and link with the ecosystem services in the study area. The Shannon-Wiener biodiversity index was calculated by

$H = \sum_{i-1}^{R} p_i \ln p_i$ p_i represent proportion of taxonomic group i in the community

R represent the number of taxonomic groups in the sample

Rice paddies have two interesting habitats for insects and other arthropods: aquatic habitat and aerial habitat (where the rice crops are exposed). Agricultural practices, such as using insecticide in the rice field, may influence the diversity of herbivorous insects and predators.

Invertebrate diversity in aquatic habitats, three sampling points were selected in each rice paddy plot. Kick net sampling method was applied for each sampling point to collect aquatic insects and other invertebrates. All invertebrates were separated from other debris and preserved in 70 % alcohol solution for further identification.

Aerial insect diversity was examined by a way of sampling with a sweep net. As all of our study rice paddy plots presented in a square shape, a sweep net was used for collecting insects associated with rice and above the rice plant from three sides of each plot. The species of the insects were identified and the number of individuals of each species were also recorded.

2.1.1 Results: Aquatic invertebrates

In total, 15 samples were taken from the conventional rice farming system while there were 26 samples from the organic rice farming system. For the conventional rice system, 676 individuals of aquatic insect were identified and were member of 24 families from 7 orders. For the organic rice system, 841 individuals of aquatic insect were identified and were member of 30 families from 8 orders. To be able to compare between the organic and conventional rice farming system, number of samples from each system should be equal. Therefore, 15 samples from the organic rice system were randomly selected from the total of 26 samples. From these samples:

i. Aquatic insects identified in the organic rice system belonged to 27 families from 8 orders. The Shannon - Weiner diversity index values of the aquatic insects in conventional and organic rice system were 2.066 and 2.071 respectively. These index values indicate that diversity of the aquatic insect in both systems were the same.

ii. A comparison in family level, aquatic insect from family **Dytiscidae** and family **Chironomidae** were the dominant families in both rice systems. The Jaccard similarity coefficient demonstrated that 59 % of overall insect families were found in both rice systems.

iii. In lentic water systems, such as flooded rice fields, aquatic insects of the Ephemeroptera, Trichoptera and Odonata (ETO) orders are generally used as indicators for water quality (DWAF, 2004). In the conventional rice system, of these three orders, insects only from order Ephemeroptera and Odonata were found, while in the organic rice system insects from all three Ephemeroptera, Trichoptera and Odonata orders were all found (table 4.5). This suggested that the two rice farming practices provided slightly different habitat quality for these insects. Although the ETO insects from both rice systems were found to belong to the same families, they differed in number of individuals. A greater number of insects from the Caenidae, Hydroptilidae, Corduliidae and Libellulidae families were found in the organic rice system than in the conventional rice system.

iv. Predatory insects form an ecological functional group of insects that can be used as an indicator of wetland ecosystem health. In these studies, the number of individuals of the predatory insects were higher in the conventional rice practice than the organic rice practice. However, predatory insect found in the organic rice farming system were from a more diverse set of families. In particular, firefly larvae (Lampyridae) and water boatman (Belostomatidae) were only found in the organic rice system. Moreover, more than two floats of individuals of dragonfly’s nymph and insects from the family Ceratopogonidae were observed in the organic rice system (table 4.6).

Table 4.5 Number of individual aquatic insects from the ETO group classified by family

Order	Family	Number of individuals	
		Found in Conventional rice paddies	**Found in Organic rice paddies**
Ephemeroptera	Baetidae	22	15
	Caenidae	5	64
	Total	**27**	**79**
Trichoptera	Hydroptilidae	-	1
	Total	**-**	**1**
Odonata	Coenagrionidae	22	19
	Corduliidae	3	9
	Libellulidae	12	23
	Unknown	-	1
	Total	**37**	**52**
Grand Total		**64**	**132**

Table 4.6 Number of individual aquatic insects from predatory family insect groups

Order	Family	Number of individuals	
		Found in Conventional rice paddies	**Found in Organic rice paddies**
Coleoptera	Dytiscidae	217	176
	Hydrophilidae	86	38
	Lampyridae	-	2
	Noteridae	28	15
	Total	**331**	**231**
Diptera	Ceratopogonidae	4	20
	Chaoboridae	5	6
	Total	**9**	**26**
Hemiptera	Belostomatidae	-	2
	Corixidae	31	4

Order	Family	Number of individuals	
		Found in Conventional rice paddies	Found in Organic rice paddies
	Gerridae	8	5
	Hydrometridae	-	1
	Notonectidae	16	2
	Pleidae	3	3
	Veliidae	2	-
	Unknown Hemiptera	-	1
	Total	**60**	**18**
Odonata	Coenagrionidae	22	19
	Corduliidae	3	9
	Libellulidae	12	23
	Unknown	-	1
	Total	**37**	**52**
Grand total		**437**	**327**

2.1.2 Results: Arthropods in aerial rice habitats (including on the rice plants)

Agricultural ecosystems, such as rice fields, provide the habitat for many insects and spiders. Rice plants are vulnerable to many herbivorous insects, which can be considered insect pests. Moreover, many invertebrate predators, such as spiders, use this ecosystem as a hunting ground.

Here, we collected aerial insects (insects living on the exposed shoots) by sweeping techniques and compared the diversity of insects in organic and conventional rice systems in Surin and Buriram provinces during September 2019.

i. Spiders and 8 orders of insects were found in both organic and conventional rice paddies. Order Coleoptera (beetles) and Order

Hemiptera (true bugs and leafhoppers) were the 2 major groups of insects in both agricultural practices (Figure 4.13).

ii. In organic rice fields, 32 families of insects were found, while conventional rice fields found 41 families. However, the higher number of insect's families in the conventional rice fields do not reflect the higher diversity of insects. To compare the similarity of insect family and the diversity of insect between the organic rice fields and the conventional rice fields, the Jaccard similarity coefficient and the Shannon-Wiener index were used, as reported below.

iii. The Jaccard similarity coefficient between two practice systems shows that the similarity of insect family was 65.91%. This means more than 50% of the insect families found in both practice systems were similar.

iv. The Shannon-Wiener diversity index was calculated to assess the richness and evenness of species in the study area. Both practice systems have similar Shannon-Wiener index values - 2.31 in organic rice field and 2.34 in conventional rice field (Figure 4.14) reflecting a similar diversity of insects.

v. After categorizing the insects by functional groups, 16 families of herbivorous insects were found in the organic system and 23 families in conventional system. However, the total number of herbivorous insects in organic fields is higher than conventional field (586 and 387 respectively). The highest number of herbivores is the weevil (O. Coleoptera, Fam. Curculionidae) in both systems (Figure 4.15). The weevil, especially rice root weevil (*Hydronomidus molitor*) is considered an important pest of rice in Thailand. However, this study found other weevils (subfamily Entiminae) instead of *Hydronomidus molitor*. The second number of herbivores is leafhopper (O. Hemiptera). Leafhoppers in family Delphacidae (brown leafhopper) and Cicadellidae (green leafhopper) are major pests of rice in Thailand. Interestingly, our results showed a greater number of leafhoppers in family Cicadellidae in the organic system (Figure 4.13). The higher number of leafhoppers may result from the prohibition on using chemical insecticides in organic practice. In conventional practice, the higher diversity of herbivorous insect families may be a consequence of the lower number of the major pests like leafhoppers which increase the opportunity for secondary pests to occupy the area.

vi. For predatory insects, we found 10 families in organic system and 12 families in conventional systems. The major predator is the ant (O. Hymenoptera, Fam. Formicidae). A greater number of damselflies (O. Odonata) were found in the conventional system. We found predatory bugs from the Nebidae family only in the organic field, while assassin bugs (Fam. Reduviidae) were found in both systems. Predaceous beetles (O. Coleoptera) and lady beetles (Fam. Coccinellidae) were found in both organic and convention fields, while ant-like beetles (Fam. Anticidae) and ground beetles (Fam. Carabidae) were not present in organic fields (Figure 4.15). The difference in some family of predators may be the result of a difference in the composition of prey (herbivores). However, the total number of predators found in organic and conventional systems are similar (100 and 106, respectively).

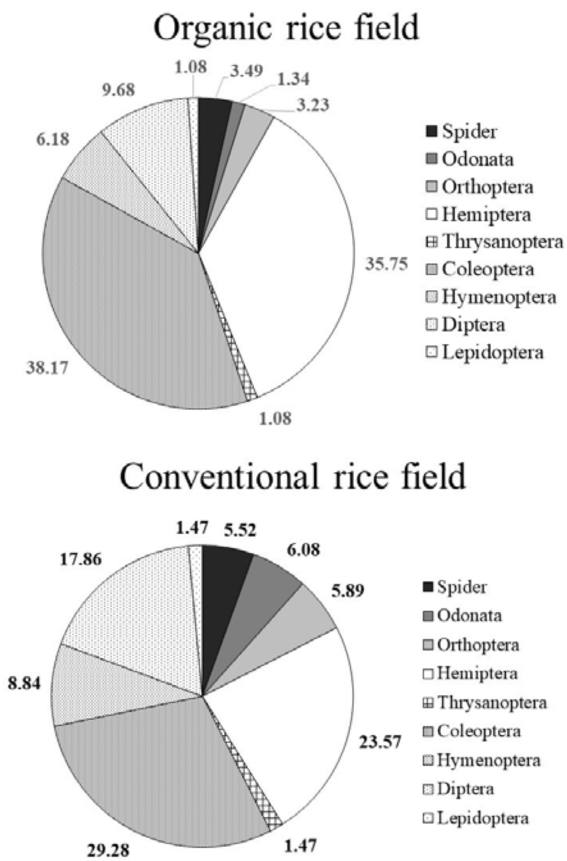


Figure 4.13 Percentage of spider and each order of insects in the aerial habitats of the organic rice system (upper) and conventional rice system (lower).

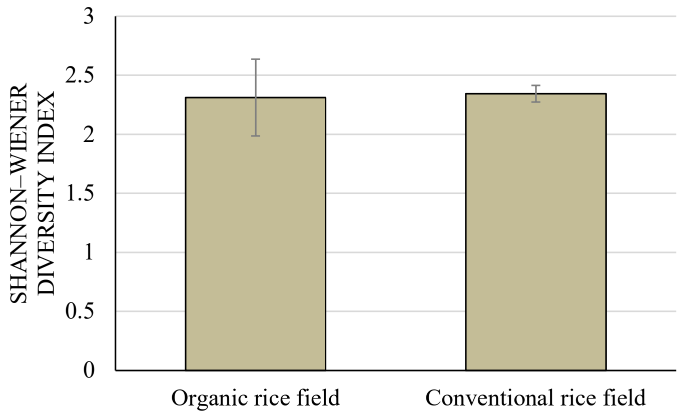


Figure 4.14 Bar chart comparing Shannon-Wiener diversity index of arthropods in the aerial habitats of organic rice system and conventional rice systems

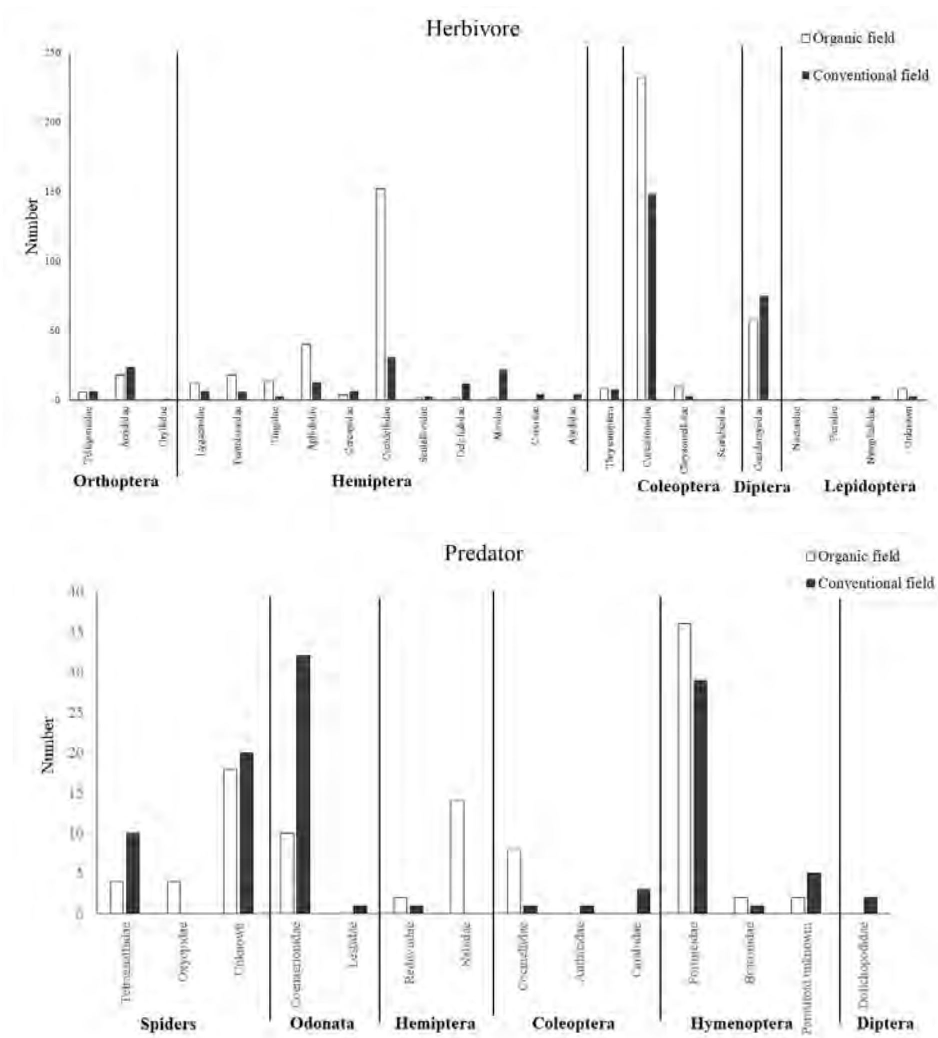


Figure 4.15 Number of arthropods in each family classified by functional group: Herbivores (upper graph) and Predators (lower graph).

2.2. Biodiversity of the other taxa between conventional and organic rice farming

The sampling of all other taxa was done in 104 sub-samples in 24 rice sites. The survey was conducted by 3 methods from the previous parts including trapping and net catching of air insect and other aquatic species in rice field. A total of 21 orders and 7 classes were found. The abundance of each order was shown separated by rice farming practice in the following table 4.7, figure 4.16, 4.17, and 4.18. Measuring the species richness, diversity and composition was conducted to determine the species diversity. Species richness was determined by counting the number of species in each plot, while the composition of community was analyzed using the principal component analysis (PCA) to reduce the large dimensional species composition data to be more interpretable using the most variability of the species. As there are many dimensions of analysis, PCA is selected as a method as it can capture a complex set of environmental variables, simplifies the dimensions, and facilitates the analysis.

Table 4.7 Abundance of each class and order of animal surveyed in sample sites within study area of organic and conventional rice farming

Class	Order	Average abundance (conventional farming)	Average abundance (organic farming)
Reptilia	Squamata	0.020 (0.141)	-
Amphibia	Anura	0.196 (1.652)	0.111 (0.520)
Actinopterygii	Anabantiformes	0.573 (4.726)	2.173 (28.618)
	Cypriniformes	0.608 (7.343)	-
Crustacea	Decapoda	0.193 (0.662)	-
Araneae	-	0.310 (0.955)	0.735 (2.708)
Gastropoda	Architaenioglossa	0.190 (0.849)	0.056 (0.660)
	Littorinimorpha	-	0.056 (0.302)
	Mesogastropoda	0.160 (0.618)	0.037 (0.272)
	Stylommatophora	0.080 (0.340)	-
Insecta	Coleoptera	2.399 (14.652)	1.402 (4.891)
	Diptera	2.189 (6.271)	2.054 (9.826)
	Ephemeroptera	0.871 (1.875)	2.485 (5.680)

Class	Order	Average abundance (conventional farming)	Average abundance (organic farming)
	Hemiptera	0.299 (1.326)	0.286 (1.417)
	Hymenoptera	0.381 (1.639)	0.238 (0.983)
	Lepidoptera	0.061 (0.314)	0.081 (0.297)
	Mantodea	-	0.048 (0.218)
	Odonata	0.609 (1.925)	0.608 (1.306)
	Orthoptera	0.195 (0.666)	0.231 (0.681)
	Thysanoptera	0.381 (1.161)	0.333 (0.966)

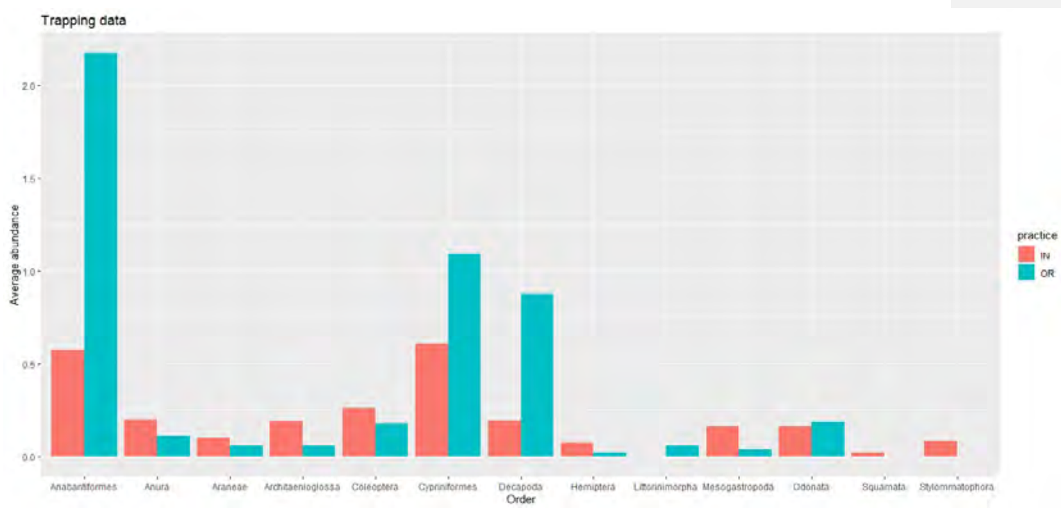
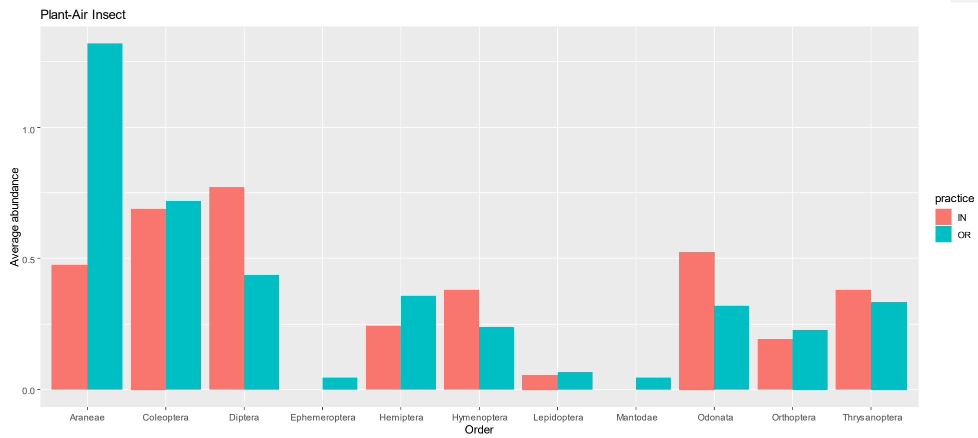


Figure 4.16 Barplot showing the mean abundance of each order of animals found in conventional (IN) and organic (OR) rice farming practice sites based on trapping data.



Araneae
Coleoptera
Diptera
Ephemeroptera
Hemiptera
Hymenoptera
Lepidoptera
Mantodae
Odonata
Orthoptera
Thysanoptera

Figure 4.17 Bar plot show the mean abundance of each order of animals found in conventional (IN) and organic (OR) rice farming practice sites based on netting methods.

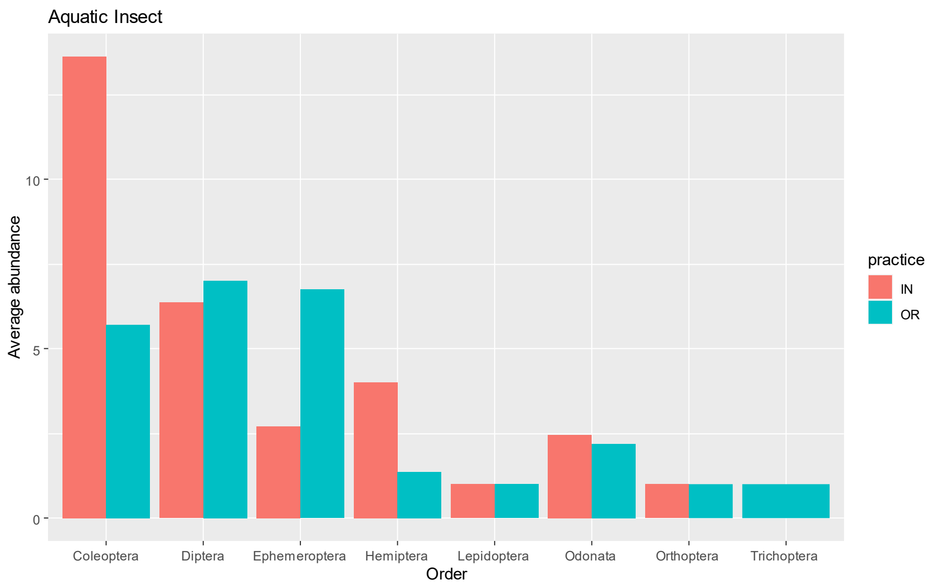


Figure 4.18 Bar plot show the mean abundance of each order of animals found in conventional (IN) and organic (OR) rice farming practice sites based on aquatic survey.

In the comparison between the feeding guilds of the insects, we found that the average abundance of both plant feeding and predatory insects was greater in conventional farming sites than in organic farming sites (see figure 4.19).

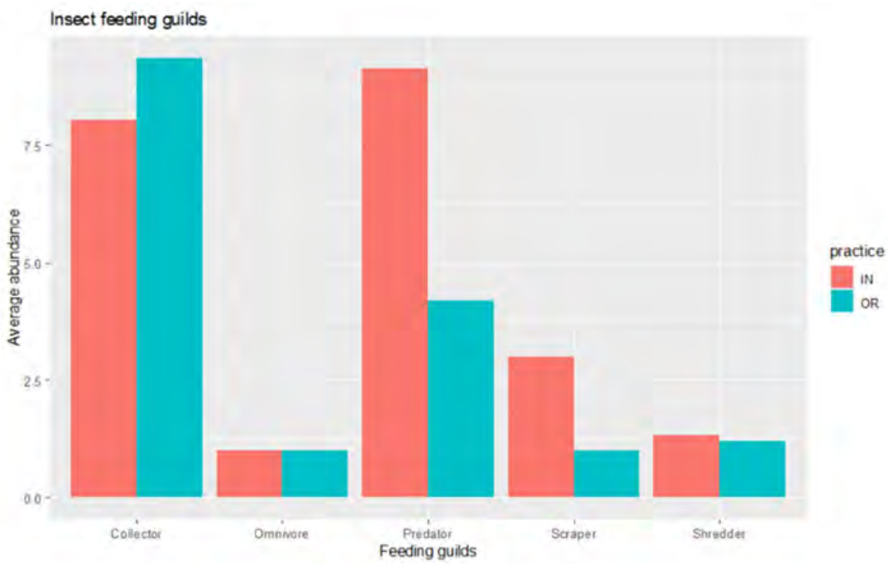


Figure 4.19 Bar plot showing the mean abundance of each feeding guilds of insects found in conventional (IN) and organic (OR) rice farming practice sites based on all surveying methods.

For the comparison of overall biodiversity between sites, the biodiversity index of Shannon-Wiener was quantified using data from field surveys of animals in both organic and inorganic rice farming. 104 sampling plots in 24 rice farming sites. The results show that the overall diversity of organic rice farming is not significantly higher at both species-level and class-level (figure 4.20 and 4.21). This was because most of the species were spatially clumped and absent from many sample plots (more than half, see figure 4.20). Nevertheless, the difference of taxonomic diversity was not identified, the average taxonomic diversity is non-significantly higher in organic rice farm.

Other studies have measured the biodiversity in both organic and conventional rice farming. Many studies found that organic agriculture fosters higher biodiversity than the conventional farming system (Chouichom and Yamao, 2010; Rahmann, 2011; Ovawanda et al, 2016). However, to gain insight between species composition and rice system structure, a food web structural analysis must be conducted to include more detailed farming practice, ecological structure, and spatial structure to determine biological structure of ecosystem (Deb, 2009).

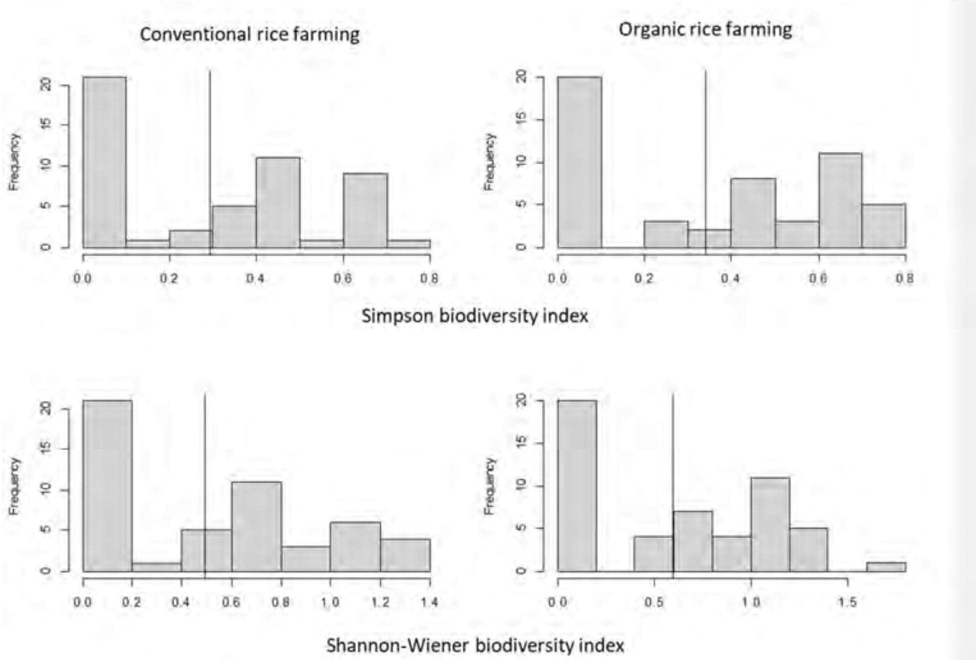


Figure 4.20 Comparison between Shannon-Wiener of taxonomic order diversity indices of organic rice farming (right) and conventional (left) rice farming

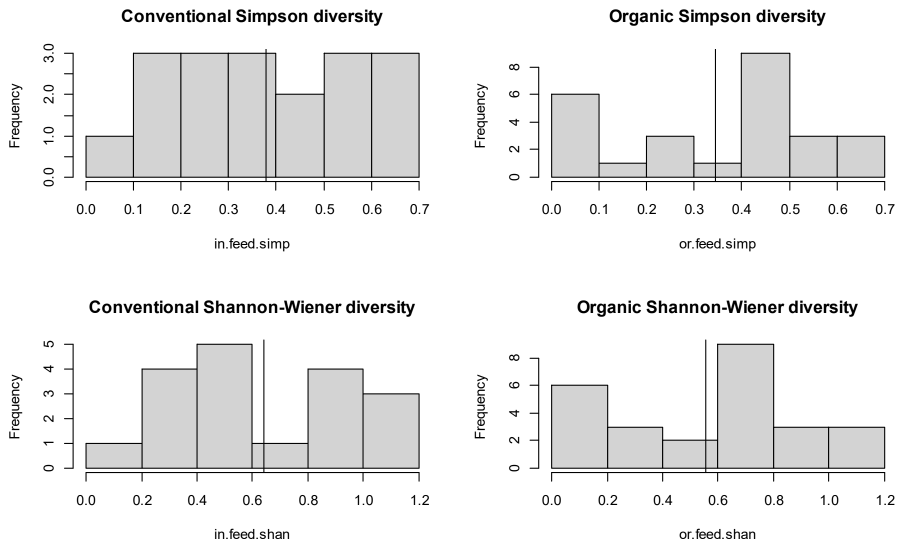
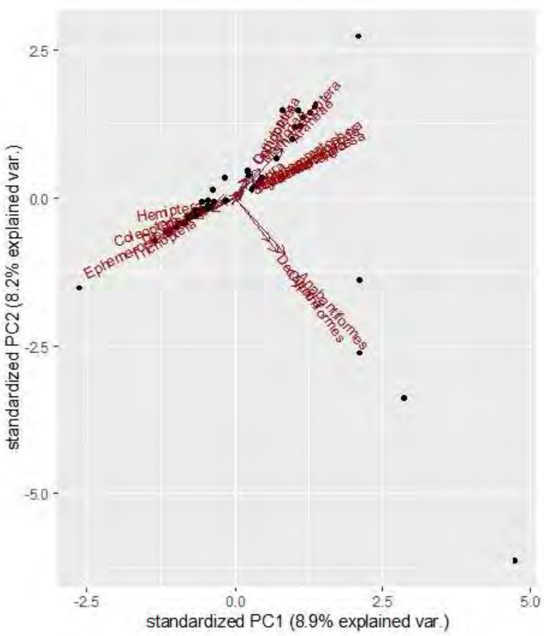
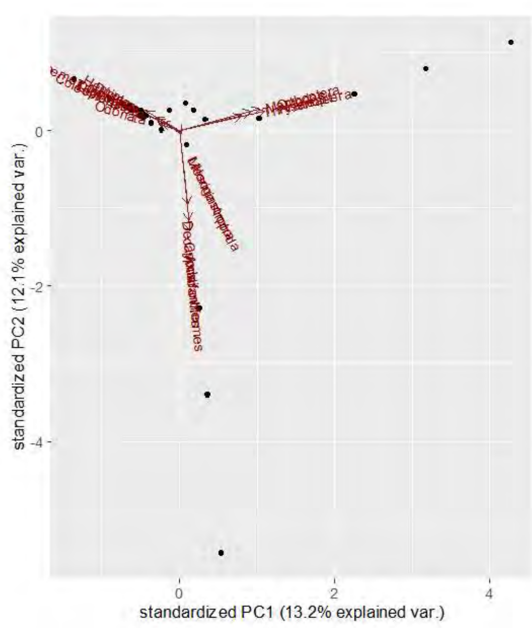


Figure 4.21 Comparison between Shannon-Wiener index on functional diversity of organic and inorganic rice farming based on feeding guilds. While the difference of functional diversity was not identified, the average diversity is non-significantly higher in organic rice farm.

2.3 Community composition between rice farming practice

The principal component analysis (PCA) was applied to identify the animal community composition of overall rice farming, conventional rice farming, and organic rice farming. The results show that each type of practice and overall had a different patterns of community composition (see Figure 4.22), while the PCA loadings, which is the coefficients of linear combinations among the abundance of taxon, show the correlation between abundance of each order and PCA axes was shown in figure 4.23. Each PCA axis represents the proportion of variability explained by PCA. The PCA axis showed that the first axis is associated with Araneae, Lepidoptera, and Thysanoptera, while is negatively associated with Odonata, Ephemeroptera, Diptera, and Coleoptera. The second axis is associated with Stylommatophora, Mesogastropoda, and Anura; while is negatively associated with Lepidoptera, Diptera, Coleoptera, and Araneae. The third axis is associated with Odonata, while is negatively associated with Stylommatophora, Mesogastropoda, Diptera, and Coleoptera.





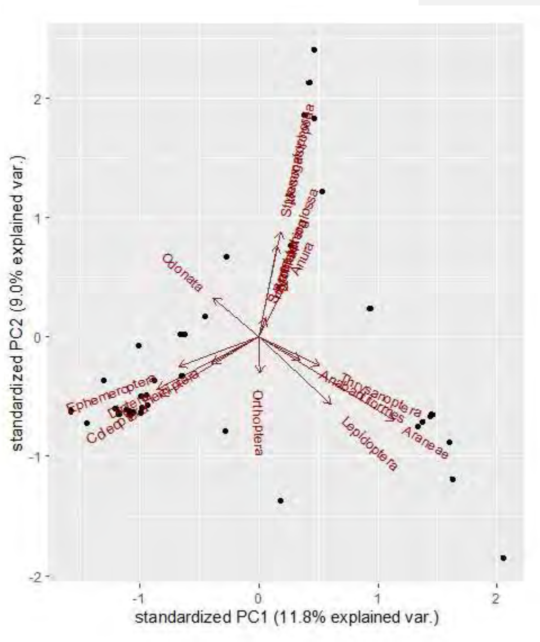


Figure 4.22 PCA biplot between PC1 and PC2 of taxonomic community composition of pooled data on overall rice farming, conventional rice farming, and organic rice farming methods.

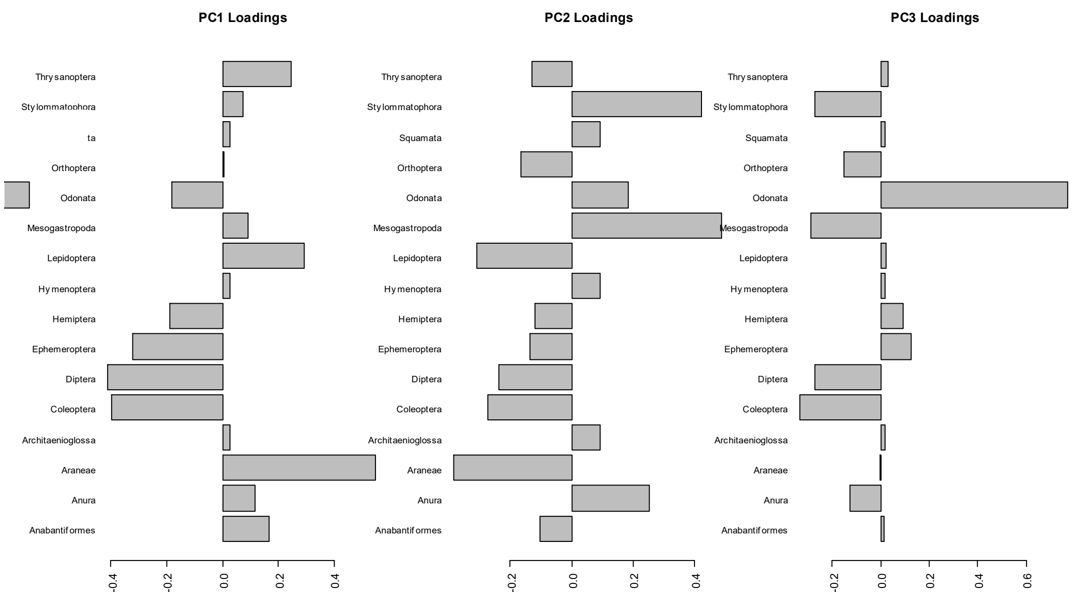


Figure 4.23 Plot of the PC scores for each species in the ordination analysis of the overall data.

2.4 Landscape analysis and prediction of rice field insect biodiversity

The prediction of biodiversity at landscape level could help policy makers to explore the collective effects of policy implementation and to identify the landscape the distinct feature such as hot-spot of biodiversity. To link the plot-based survey data to the biodiversity at landscape level, the averaged effects of overall biodiversity is needed to be quantified to represent the biodiversity at the locations of sampling sites. The relationship between known landscape covariates and averaged biodiversity responses needs to be quantified in order to predict the biodiversity responses at the unknown locations. Covariates at landscape level were land use, elevation, slope, terrain position index (tpi), and 4 landscape level metrics calculated using raster (Hijmans and Etten, 2012) and landscape metrics (Maximilian et al. 2019) package in R including mean core area, patch richness, joint entropy, and patch density of the land use type at the position of study plots. The landscape metrics represent the structural characteristics of landscape, e.g. habitat fragmentation, connectivity, etc., is related to the composition of ecosystem in the spatial context resulting in different patterns of biodiversity (Fahrig, 2003).

The raster of covariates was prepared with a resolution of 270 meters. The study area covers the whole northeastern region of Thailand. Therefore, to alleviate the effects of extrapolation, we acquired the secondary data from two other studies in the region that surveyed and compared insect biodiversity between conventional farming and organic farming (Jiaphasuanan, 2020; Thongphak & Boonthai Iwai, 2016). Both studies had the study sites located in Khon Kaen, Kalasin, Sri Saket, Yasothorn, and Ubon Rachathani provinces consist of 31 samples. To deal with the inconsistency caused by sampling methods among studies, the normalized value of Shannon-Wiener diversity index was calculated and used as a response of the model rather than an absolute value. In this analysis, the normalized Shannon-Wiener diversity index was used because the data was from the different studies with different sampling methods. The normalized values of biodiversity index represented the relative value of site-specific biodiversity index compared to other site of the same study. The covariates of the whole study area are shown in figure 4.24. Random forest model was used to train data of normalized diversity index among the studies based on the landscape covariates. The modeling processes was done using Forest package (Breiman, 2001) under statistical software R (R Core Team, 2020). The spatial analysis was done at 300-m resolution with the WGS84 UTM zone 48N coordinate system.

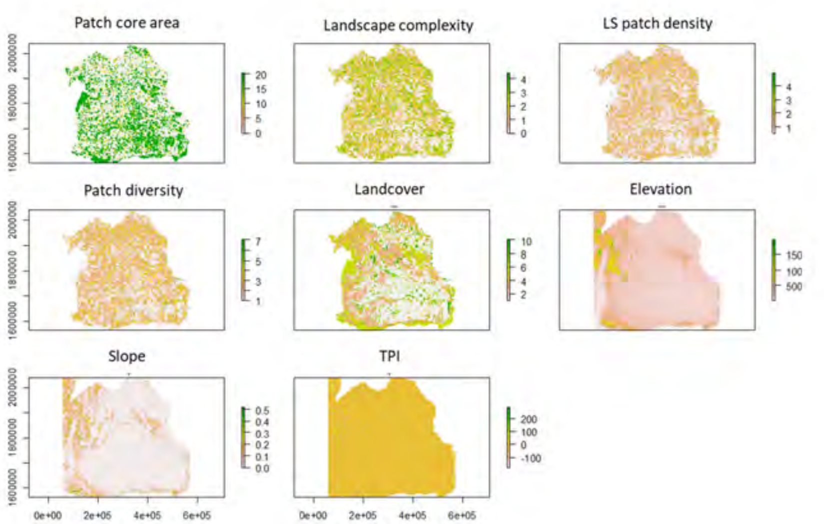


Figure 4.24 Eight landscape covariates as the exploratory variables of Random Forest model composed of 4 moving windows covariates (lsm), land use, digital elevation model, slope, and terrain position index.

From the results of Random Forest Model, we are able to predict the normalized diversity index at the landscape level using the landscape covariates and current land use data. The accuracy of the model and predicted normalized diversity index at the landscape level from the present data (2020) are shown in Figure 4.25. Based on the prediction, most of the organic farming practice sites had higher diversity index than the predicted sites using conventional methods, see figure 4.26. On this basis, we predict the diversity index for each scenario, as described in the next section.

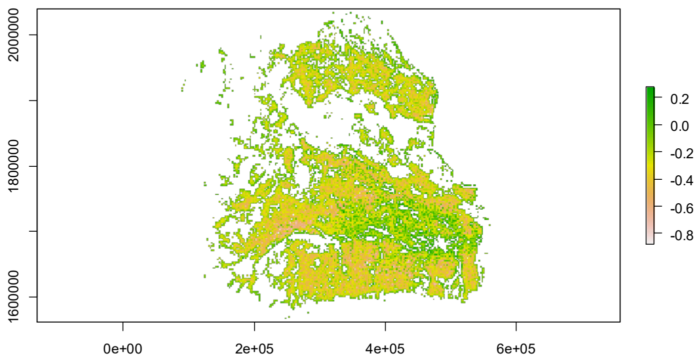


Figure 4.25 Prediction map of normalized biodiversity index of Shannon-Wiener of rice field landuse for the whole region of northeastern Thailand for 2020.

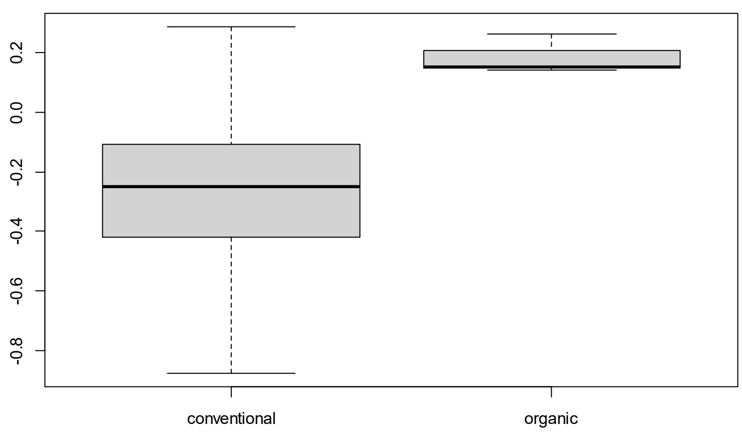


Figure 4.26 Distribution of normalized Shannon-Wiener diversity index of the predicted landscape averaged across 2020 to 2035 of the northeastern region of Thailand.

2.5 Prediction the normalized biodiversity index for future scenarios

The prediction of the future scenarios of the landcover change model 1, 2, 3, and 4 was done using the calibrated random forest model from the previous results. The Random Forest is a machine learning method by averaging over the ensemble multiple regression/classification tree. The prediction of year 2020, 2025, 2030, and 2035 was done to see the change and compare biodiversity index across scenarios. The predicted maps of normalized biodiversity based on the 4 future landcover scenarios are shown in Figures 4.27 and 4.28 and the summary of the predicted biodiversity index are shown in Table 4.8. From the results of this prediction, the biodiversity increased as the percentage of land practiced in organic rice farming increase from 2020 to 2035 with scenario 3 and 4 had the higher rate of increase of normalized biodiversity index than scenario 1 and 2 throughout time (figure 4.28) based on the higher increment rate of conversion to organic rice farming.

The results of the prediction are in agreement with literature suggesting positive effects of organic farming on biodiversity. It is expected that the organic practice provide benefits on biodiversity of multiple taxonomic groups over large areas (Elphick et al., 2010; Katayama et al., 2019). Nevertheless, the other landuse practice must be considered in the analysis with farming practices e.g. land conversion, irrigation system, subsidy on conservation (Katayama et al, 2015) in order to precisely predict the effect on the conservation of biodiversity at landscape level. The practices that involve protecting the habitats may be incorporated into rice farming system for effective biodiversity conservation.

Table 4.8 Mean and standard deviation of the normalized biodiversity index in rice farming landcover of the whole region. The mean was calculated across scenarios and projected years of 2025, 2030, and 2035.

Scenario	Normalized Biodiversity Index			
	2020 (present)	2025	2030	2035
Current	-0.259 (0.186)	-	-	-
Scenario 1	-	-0.162 (0.124)	-0.162 (0.124)	-0.162 (0.124)
Scenario 2	-	-0.154 (0.128)	-0.147 (0.133)	-0.138 (0.138)

Scenario	Normalized Biodiversity Index			
	2020 (present)	2025	2030	2035
Scenario 3	-	-0.130 (0.143)	-0.0882 (0.162)	-0.0484 (0.172)
Scenario 4	-	-0.129 (0.144)	0.0759 (0.146)	0.0759 (0.146)

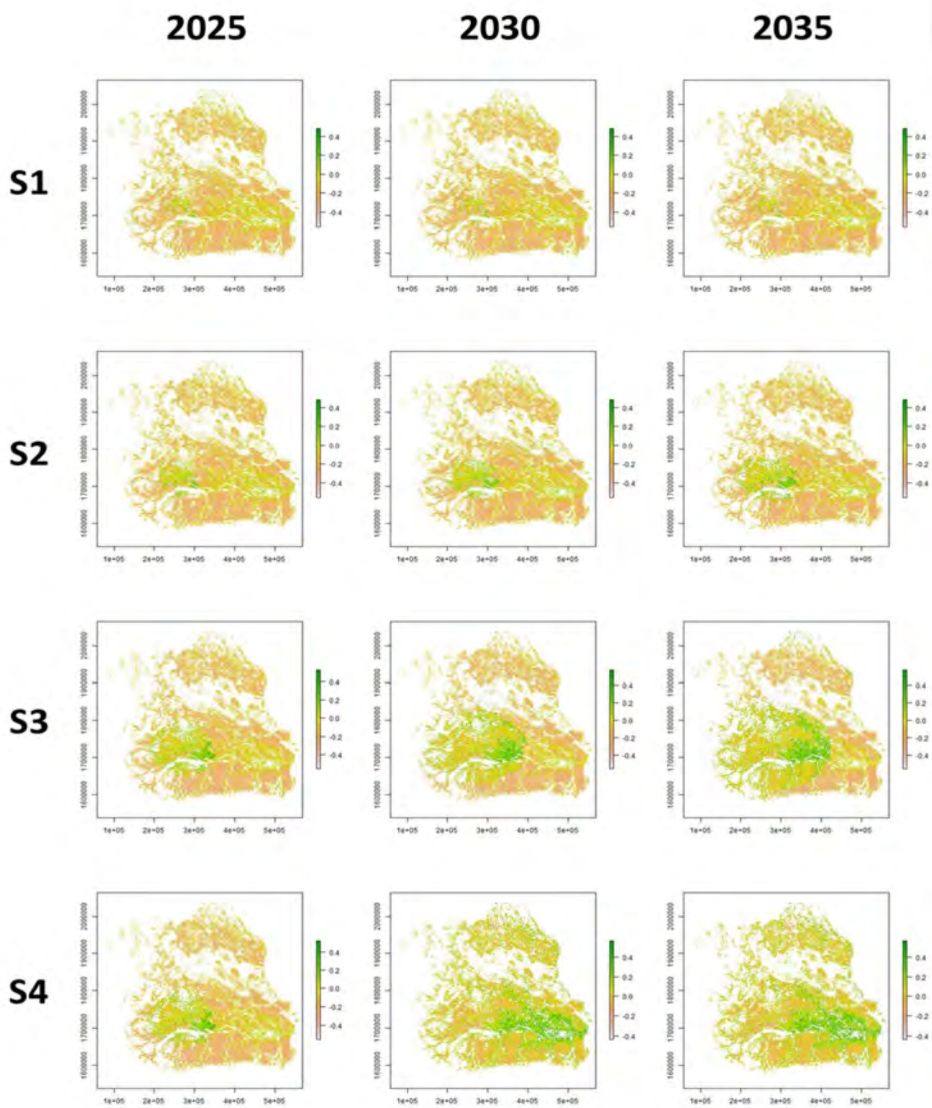


Figure 4.27 Landscape interpolation of normalized biodiversity index values across 4 landcover change scenarios for years 2025, 2030, and 2035

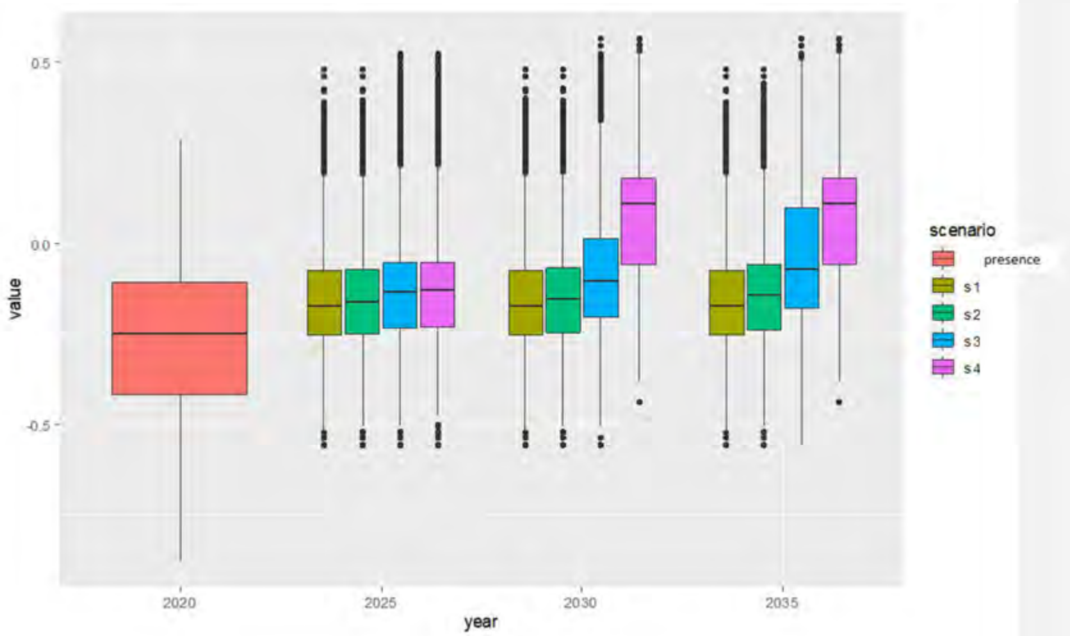


Figure 4.28 Box plot showing predicted normalized biodiversity index of the whole landscape in the northeast of Thailand for selected years in all scenarios using Random Forest model

2.6 Quantifying the relationship between rice farming practices, biodiversity, yield and cost

To quantify the relationship between rice farming practices, the latent variables of biodiversity and yield/cost of rice farming were identified and modeled using Bayesian framework. The biodiversity was then merged with the household survey data to create the model. The parameters for the Bayesian model included the average effect of both rice cultivation practices on biodiversity (β) and the latent average effect of biodiversity on yield/cost ratio (γ) were used as parameters for the model. All of the data variables were rescaled to fit the normal processes of the modeling framework. The model was fitted using Gibbs sampling methods of Markov chain – Monte Carlo in STAN program running on R interface via rstan package (Stan Development Team, 2020).

Data variables

i = biodiversity samples from field data, j = economic samples from household survey data

x_i and x_j = Practice; 0=conventional, 1=organic at i and j

y_i = observed biodiversity index at i

z_j = observed yield/cost at j

Model variables

Parameters

β = average effect of practice on biodiversity

γ = average effect of biodiversity on yield/cost

Latent

μ_i = latent biodiversity index at i

λ_j = latent yield/cost ratio at j

σ_μ^2 = normal process variance of biodiversity index at j

σ_λ^2 = normal process variance of yield/cost ratio at j

Model framework

1. *Model from biodiversity side*

$$y_i \sim Normal(\mu_i, \sigma_\mu^2)$$

$$\mu_i = \beta x_i$$

Then derive $y_j \sim Normal(\mu_j, \sigma_\mu^2)$

Given, $\mu_j = \beta x$

2. *Model from yield/cost side*

$$z_j \sim Normal(\lambda_j, \sigma_\lambda^2)$$

$$\lambda_j = \gamma y_j$$

From the results, two parameters were quantified relating to the effect of different rice systems practices (how rice farming practice affect the biodiversity) on biodiversity (β), see figure 4.28, and the effect of latent biodiversity of economic sampling on the yield/cost ratio (γ), see figure 4.29. The results showed that while the different practices have a significantly positive (the posterior does not overlap zero) influence on biodiversity, the effect of latent biodiversity on the yield/cost ratio was not statistically significant. There are a few other studies that show the relationship between agro-biodiversity and the reduction in abundance of pest species in the regions which could implied the reduction of cost on pesticide (Maneepitak, 2007; Hidaka et al., 1974), However, the biodiversity parameters in this study could not be used to assess the difference in profit and cost between organic and conventional practices, due to mismatching between most of the farming household questionnaire dataset and the biophysical sampling dataset.

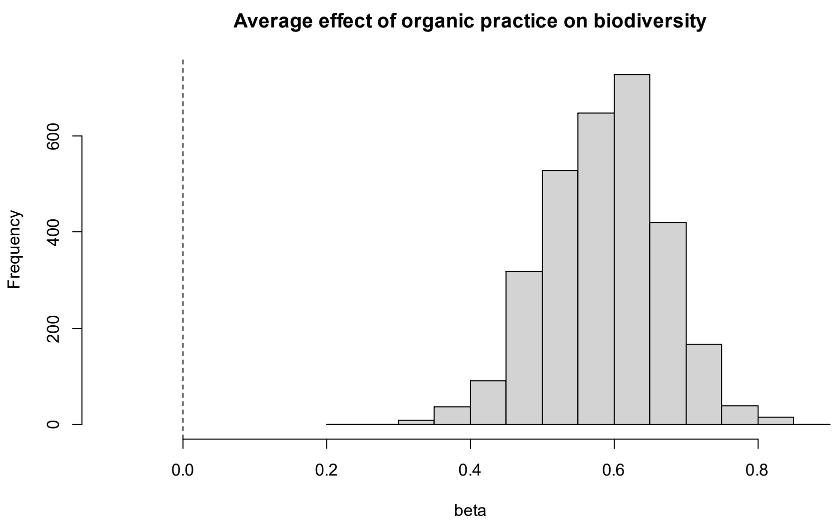


Figure 4.29 The posterior distribution of average effect of organic practices on normalized biodiversity.

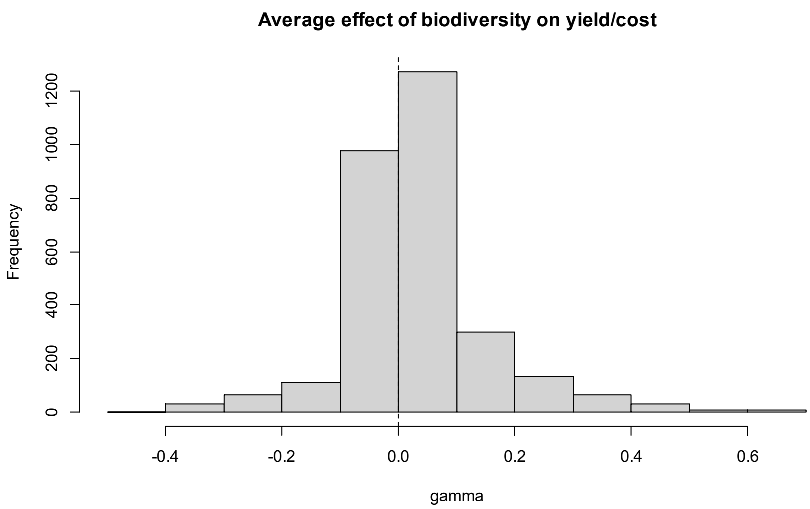


Figure 4.30 Posterior distribution of average effect of normalized biodiversity on yield/cost. The graph shows non-significant difference from zero of average effect of biodiversity on yield-cost ratio.

3. Greenhouse gas emissions and soil organic carbon stock

The aim of this section of the study is to conduct a spatial analysis of greenhouse gases (GHG) emissions from organic and conventional rice practices in Northeast of Thailand, and project how these will change in the future under different policy intervention scenarios. The three main sources of GHG emissions from the rice fields are focused. The first one is GHG emissions that are generated directly during cultivation, the flooding of the rice fields, are a major source of methane (CH_4) gas emissions. The paddy fields in Northeast of Thailand are mostly rain-fed, and therefore there is limited scope to prevent flooding during the rainy season, and farmers have limited control over water management. Flooding is also considered a useful means of weed control without external inputs and creates environments for fish and other sources of protein for rural diets. Rice cultivation processes also generate to a lesser extent nitrous oxide (N_2O) emissions. The second source of GHG emissions in rice field is from the soil, which is related to soil carbon stocks.

The third source of GHG emissions in rice field focused in this study is the post-harvest activity, rice straw burning, that generates GHG emissions and air pollution, which is widely performed in conventional rice practice. However, field burning is prohibited for organic rice practice. In addition, soil organic carbon (SOC) stocks, the capability of the soils for GHG removal, of organic and conventional rice practices is also estimated in this section.

3.1 Greenhouse gas emissions and soil carbon stock during cultivation of conventional and organic rice practices

For estimating GHG emissions and SOC, the Denitrification-Decomposition (DNDC) model is employed. The DNDC model is a process-based model that can predict GHG emissions (methane: CH_4, and nitrous oxide: N_2O) in agricultural area (Figure 4.31). The DNDC model is universally used and developed to simulate SOC and GHG emissions in rice fields (Cha-un et al., 2017; Minamikawa et al., 2016; Cha-un et al., 2015; Katayanagi et al., 2012; Pathak & Wassmann, 2005).

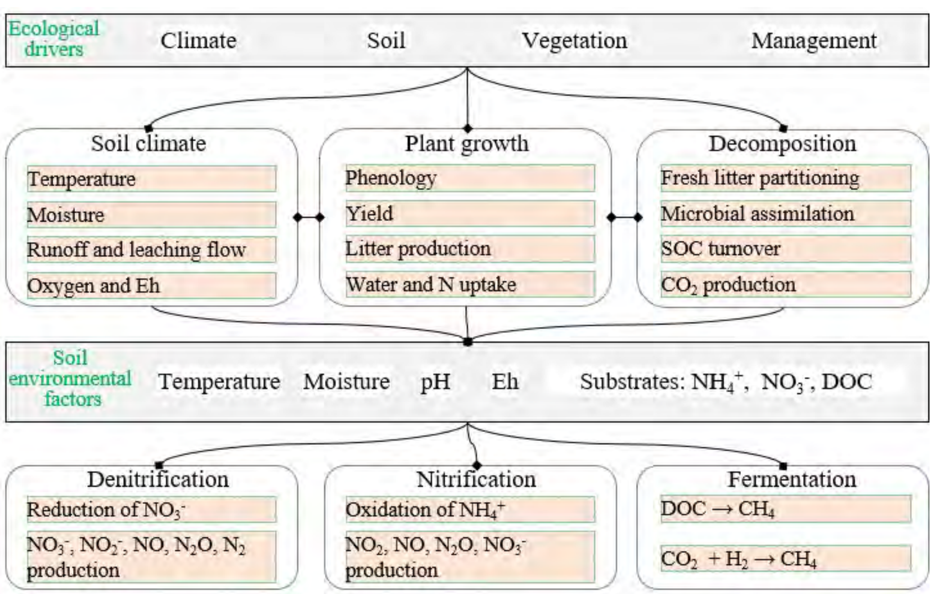


Figure 4.31 Structure of the DNDC Model (Li, 2016, as cited in Yin et al., 2020)

The DNDC model (version 9.5) is used to estimate soil organic carbon (SOC) stocks under different rice cultivation practices (conventional and organic) at the present year (2019) and predict the long-term change in SOC stocks from 2020 to 2035. Like SOC stock estimation, the model is applied to estimate GHG emissions (CH_4, and N_2O) and rice production in 2019 as a baseline and the future simulation (2020-2035).

For the initial simulation, the DNDC model runs a spin-up for 19 years (2000-2019) in order to set as a steady state. The dataset of climate for the spin-up simulation, the baseline simulation (2019) and the future simulation (2020-2035) 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). The soil datasets used in the DNDC model are soil physical and chemical properties datasets from the Land Development Department (LDD) of Thailand. The physiological data of crop datasets in each management system is described in the section below. The future simulation from 2020 to 2035 uses the soil and crop datasets in year 2019.

3.1.1 GHG assessment materials and methods

Sites and design

The study fields are in the rice paddy area located in the northeast region of Thailand. In 2019, more than 98% of the paddy fields in the region were classified as conventional rice field management and less than 2% of the fields were under organic practice.

The 7 sites studied were selected from the published data provided by the office of agricultural economics (OAE), Ministry of Agriculture and Cooperatives. Cumulatively, provinces selected for analysis cover more than 50% of the total harvest area of the northeast region in 2019 (Table 4.9). The results from these selected sites were used to calculate the results for the whole region, the northeast region of Thailand.

Table 4.9 Selected study sites in different regions and provinces.

Region	Provinces	Harvested area (ha)
1. Upper-Northeast	Khon Kaen	261,567
	Sakon Nakhon	329,507
	Udon Thani	299,140
2. Lower-Northeast	Ubon Ratchathani	579,439
	Roi-et	393,284
	Nakhon Ratchasima	329,139
	Surin	460,882

Model input

1) Soil data

The soil data were compiled from the database and published reports of the Land Development Department (LDD) of Thailand. The soil data set included soil texture, clay fraction, bulk density (BD), pH, and soil organic carbon (SOC) at the surface. Soil properties from the 7 studied sites are summarized in Table 4.10.

Table 4.10 Soil properties of the seven studied sites

Region	Provinces	Soil series	Soil texture	BD (g cm^3)	pH (1:1 water)	Clay fraction (0-1)	SOC (kg C/kg soil)
1. Upper-Northeast	Khon Kaen	Pu	LS	1.48	5.2	0.06	0.0087
	Sakon Nakhon	Pp	SL	1.54	5.3	0.09	0.0090
	Udon Thani	Pp	SL	1.54	5.3	0.09	0.0090
2. Lower-Northeast	Ubon Ratchathani	Kmr	SL	1.36	4.8	0.09	0.0029
	Roi-et	Msk	LS	1.40	5.4	0.06	0.0050
	Nakhon Ratchasima	Ki	SL	1.45	7.0	0.09	0.0064
	Surin	Ndg	L	1.65	5.5	0.19	0.0087

Soil series: Pu = Phuphan series, Pp = Phon Phisai series, Kmr = Khemarat series, Msk = Maha Sarakham series, Ki = Kula Ronghai series, Ndg = Nondaeng series

Soil texture: LS = Loamy sand, SL = Sandy loam, L = Loam

2) Climate data

The DNDC model required daily climate data. The daily maximum and minimum air temperatures, and the daily precipitation were used. The model required a 20-year spin-up time (Fumuto et al., 2008; Minamikawa et al., 2016; Cha-un, 2021) and a future simulation time. Climate data in 2000 to 2019 were used as a spin-up time and climate data in 2020 to 2035 were used as a future projection. Daily climate data sets (2019-2035) of the studied sites obtained from the EC-EARTH model RCP 4.5 and averaged climate data over 2019-2035 of the studied sites is presented in Figures 4.32.

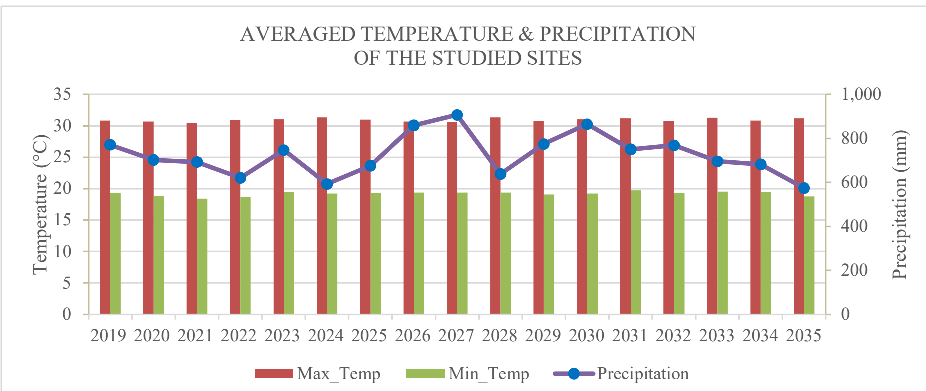


Figure 4.32 Averaged daily maximum and minimum temperature and yearly precipitation over 2019-2035 of the studied sites

3) Crop management data

The DNDC model parameters of crop and field management practices for the simulations are shown in Table 4.11.

Table 4.11 The parameters of crop and field management practices

Crop and field management	Conventional practice	Organic Practice
Cropping	Rain-fed rice	
Crop calendar (month/date)	Planting (Jul/1)	
	Harvesting (Nov/30)	
Rice grain yield[a] (kg ha^{-1}yr^{-1})	Upper-Northeast: Khon Kaen: 1,981.25	
	Upper-Northeast: Sakon Nakhon: 2,081.25	

Crop and field management	Conventional practice	Organic Practice
	Upper-Northeast: Udon Thani: 2,231.25	
	Lower-Northeast: Ubon Ratchathani: 2,250	
	Lower-Northeast: Roi-et: 2,150	
	Lower-Northeast: Nakhon Ratchasima: 2,275	
	Lower-Northeast: Surin: 2,337.50	
C content of grain yield[b] (kg C ha^{-1} yr^{-1})	Upper-Northeast: Khon Kaen: 884.63	
	Upper-Northeast: Sakon Nakhon: 929.28	
	Upper-Northeast: Udon Thani: 996.25	
	Lower-Northeast: Ubon Ratchathani: 1,004.63	
	Lower-Northeast: Roi-et: 959.98	
	Lower-Northeast: Nakhon Ratchasima: 1,015.79	
	Lower-Northeast: Surin: 1,043.69	
Land preparation (month/date)	1st Ploughing with disk or chisel, 10 cm (Jun/1)	
	2nd Ploughing slightly, 5 cm (Jun/30)	
Chemical fertilizer[c] (kg N $ha^{-1}yr^{-1}$)	1st NPK: 16-16-8 (20)[d]	-
	2nd NPK: 15-15-15 (18.75)[d]	-
Weight of Cow manure applied[e] (kg $ha^{-1}yr^{-1}$)	625	1,875
Carbon content of Cow manure applied[f] (kg C $ha^{-1}yr^{-1}$)	362.5	1,087.50
Nitrogen content of Cow manure applied[f] (kg N $ha^{-1}yr^{-1}$)	18.125	54.375
Flooding (water depth and period of flooding (month/date))	Continuous flooding, 10 cm (Aug/1 - Nov/1)	

[a] The average rice yield of each province in 2019 from Office of Agricultural Economics (OAE, 2019)
[b] Calculated from the C and N content, and C:N ratio of the grain yield percentage (Cha-un et al., 2017)
[c] Based on the recommendation of the Rice Department (RD, 2019)
[d] The compound fertilizer NPK is a combination of $N:P_2O_5:K_2O$
[e] Calculated from the average amount applied by respondents to the household survey described in section 6.
[f] Calculated from the C and N content, and C:N ratio of dry cow manure (Cha-un et al., 2015)

Model validation

In order to examine the model reliability, Annual rice yields of the studied sites (7 provinces) provided by the office of agricultural economics (OAE), Ministry of Agriculture and Cooperatives was used to simulate and validate the changes in rice grain yield. The results of the comparison analysis between the existing data from OAE and the DNDC simulation yielded coefficients of determination (r^2) of 0.55

3.1.2 Results

Long-term SOC stock estimations under different rice field management practices

The SOC stocks over 2019-2035 under different rice field management practices including conventional and organic practices are shown in Figure 4.33. The SOC stock from organic rice field tend to be higher than from conventional rice field. The carbon comprises about 50%-58% of organic matter (Pribyl, 2010); therefore, the increase of organic matter into soil results in the increase of SOC. As a greater amount of organic matter such as manure was added into the soil than in conventional rice field (Table 4.11), the greater SOC stocks are presented in organic rice field. Similarly, Arunrat *et al.* (2020) presented that several organic matter such as rice straw applied for soil amendment increased SOC accumulation.

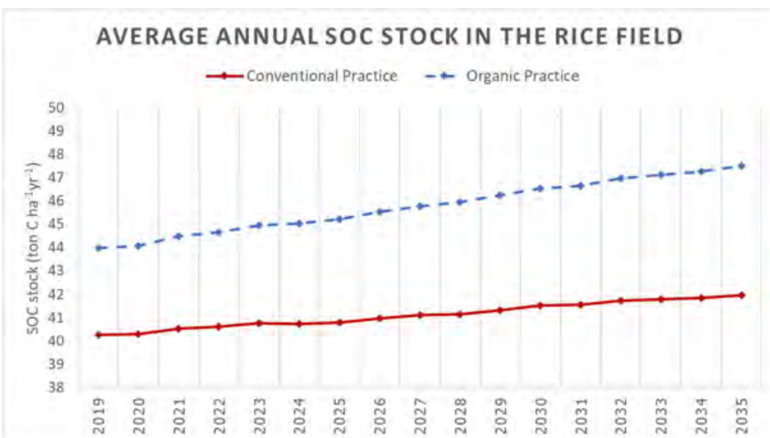


Figure 4.33 Average annual SOC stock in conventional and organic rice field management practices over 2019-2035

Long-term GHG emission estimations under different rain-fed rice field management practices

CH_4 emissions from rain-fed rice fields

Annual CH_4 emissions from conventional and organic rice field management practice over 2019-2035 under different rice field management are shown in Figure 4.34. The results from the model prediction show that organic rice fields tend to generate approximately 7% higher CH_4 emissions than conventional rice field management practice. The high organic matter input in the organic rice fields can provide the high C source for microorganisms that produce methane (methanogens) resulting in increasing the potential for generating methane. Similarly, Qin et al. (2010) showed that CH_4 emission from organic rice fields relative to conventional rice field were significantly higher especially under continuous flooding regime since decomposition of organic matter in rice fields offered the source of methanogenic substrates to promote CH_4 production over the rice-growing season.

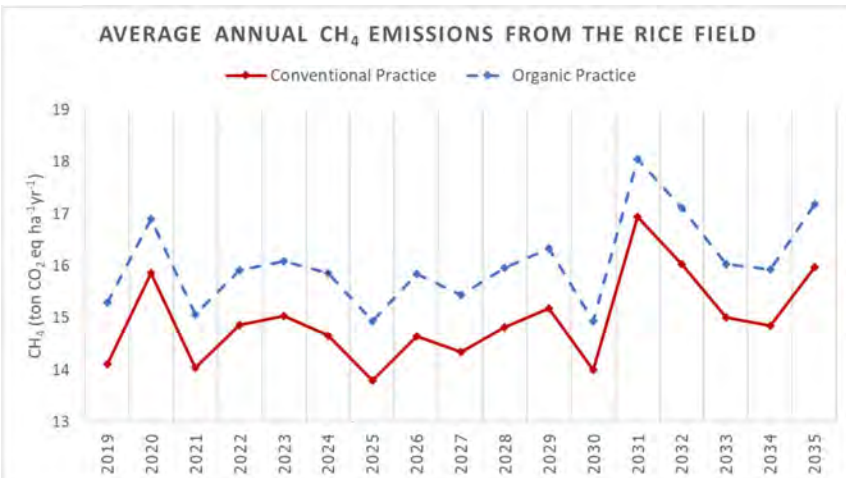


Figure 4.34 Average annual CH_4 emissions from conventional and organic rice field management practice over 2019-2035

***N_2O emissions from* rain-fed rice fields**

Nitrogen from chemical fertilizer and manure are the N sources to provide substrate for soil microorganisms involved in nitrification and denitrification, which is the important factor affecting N_2O emissions. Soil organic matter (SOM) is also an N source for producing N_2O (Aguilera et al., 2013; Yin et.al., 2020). If these N sources can be retained in the soil and the environment is suitable for soil nitrification or denitrification, the N_2O will be produced. Conversely, if the N substrate is lost from the soil through leaching or plant use, the N_2O production will be decreased. Figure 4.35 shows that N_2O emission from conventional rice field is higher than from organic rice field. This may be because the manure in the organic rice field provides lower available N such as nitrate than the chemical fertilizer in conventional systems.

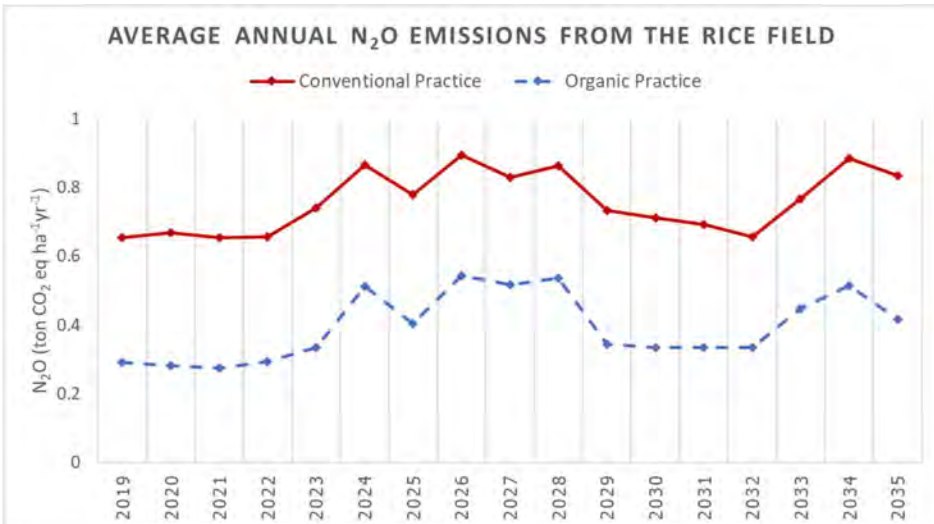


Figure 4.35 Average annual N_2O emissions from conventional and organic rice field management practice over 2019-2035

Total GHG emissions (CH_4 and N_2O emissions)

The total GHG emissions combine the projected emissions of CH_4 and N_2O (as reported in sections 2.1-2.3 above). Since CH_4 emission is the dominant GHG emission in this study, the trend of GHG emissions graph (Figure 4.36) mostly is similar to the graph of the projected CH_4 emission (Figure 4.34). This relates to previous studies which presented that paddy rice fields are one of the major sources of CH_4 emission from soil (IPCC, 2002; Jain et al., 2014; Win et al. 2020).

Since the CH_4 is the dominant GHG emission in the rice field, controlling CH_4 production should be considered. CH_4 is produced under anaerobic or flooding condition. Therefore, reduction of flooding period can inhibit the CH_4 production (methanogenesis). Qin *et al.* (2010) showed that CH_4 emission was significantly decreased by mid-season drainage and then remained at a lower release rate relative to the water regimes of continuous flooding. Thuy et al. (2018) presented that

CH_4 emission from the paddy fields with alternate for wetting and drying condition decreased 59.1 % compared to the continuous flooding condition. Therefore, water management is a key to mitigate CH_4 emission.

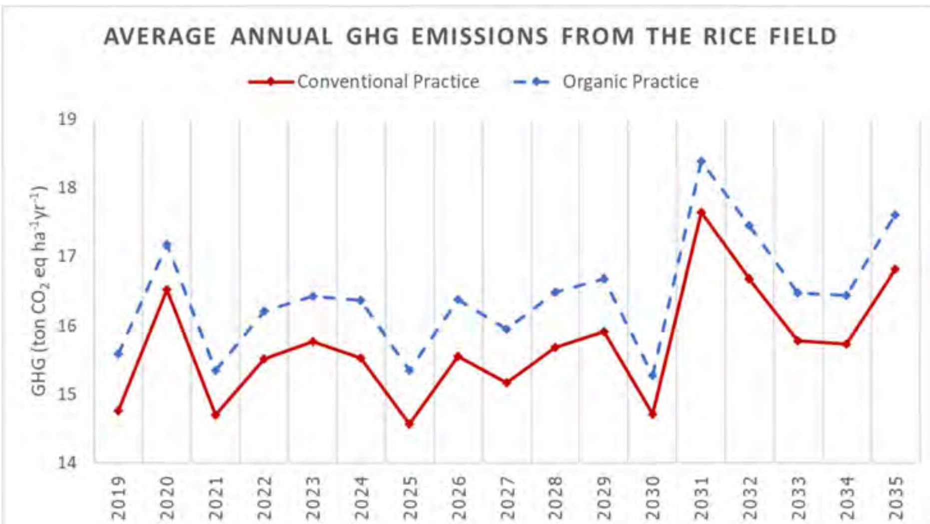


Figure 4.36 Average annual GHG emissions from conventional and organic rice field management practice over 2019-2035

3.2 GHG emissions from cultivation based on scenario analysis

As described earlier, four scenarios have been put forward for assessment including 1) Business as Usual (BAU) scenario, 2) One million rai organic rice promotion continued, 3) Enhanced organic rice promotion, and 4) Transformational change towards sustainability. Results from these assessments are summarized for the years 2019, 2025, 2030, and 2035 (Table 4.12 - 4.13 and Figure 4.37 - 4.38). This section presents a summary of the above results with reference to the four scenarios, starting with SOC stocks, and CH_4 and N_2O emissions from rice fields.

Based on the model projections, the annual SOC stocks from the rice fields in the northeast of Thailand in each scenario, combining totals from both conventional and organic rice fields, are presented in Table 4.12 and Figure 4.37. Within the same year, Scenario 4 has greater annual SOC stocks than other scenarios about 0.1% to 13% because of the increase in organic matter input from the increased area of organic rice fields. Considering the same scenario, SOC stocks increased every year, but the rates of SOC increase varied. That depended on the carbon input and the effect of the environment of each year.

Table 4.12 Annual SOC stocks from the conventional and organic rice fields in the northeast of Thailand in each scenario

Year	Soil Organic Carbon Stock (Mt C yr^{-1})			
	BAU	Scenario 2	Scenario 3	Scenario 4
2019	250.856	250.856	250.856	250.856
2025	255.797	256.666	259.494	259.668
2030	261.133	263.200	270.730	292.541
2035	264.673	268.137	281.207	299.292

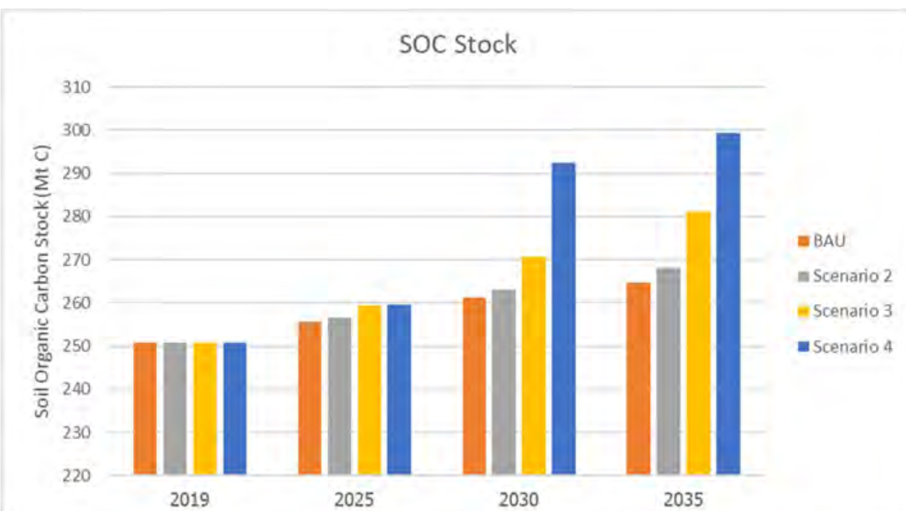


Figure 4.37 Annual SOC stocks from the rice fields (conventional and organic fields) in Northeast of Thailand in 2019, 2025, 2030, and 2035

Considering GHG emissions from only the rice fields in cultivation, CH_4 is the largest contributor of GHG emissions from the rice fields in the northeast of Thailand. The highest CH_4 emission is from Scenario 4 while the lowest CH_4 emission is from the Business as Usual (BAU) scenario. Within the same year after 2019, annual CH_4 emission from Scenario 4 are higher than other scenarios about 0.04% to 7.2% because Scenario 4 has greater C source from the organic practice to generate CH_4 than other scenarios.

However, annual N_2O emissions at the same year show the differences after increasing organic rice practice. Annual N_2O emissions from Scenario 4 are lowest than other scenarios about 0.3% to 7.2% because inorganic N source from chemical fertilizer is reduced. Annual emissions results are shown in Tables 4.13 to 4.14 and Figures 4.38 to 4.39

Table 4.13 Annual CH_4 and N_2O emissions from the conventional and organic rice fields in the northeast of Thailand according to each scenario for 2019, 2025, 2030 and 2035

Year	GHGs Emission (Mt CO_2 eq yr^{-1})							
	BAU		Scenario 2		Scenario 3		Scenario 4	
	CH_4	N_2O	CH_4	N_2O	CH_4	N_2O	CH_4	N_2O
2019	91.775	4.381	91.775	4.381	91.775	4.381	91.775	4.381
2025	87.743	4.969	87.940	4.899	88.559	4.674	88.597	4.660
2030	89.387	4.762	89.758	4.622	91.100	4.122	95.127	2.535
2035	101.779	5.575	102.488	5.323	105.166	4.370	109.081	3.013

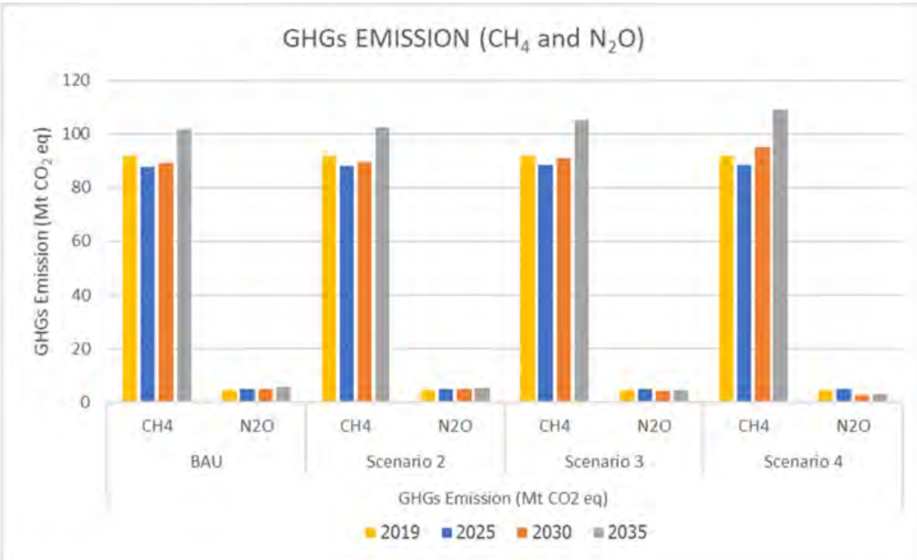


Figure 4.38 Annual GHGs emission (CH_4 and N_2O) from the rice fields (conventional and organic fields) in Northeast of Thailand in 2019, 2025, 2030, and 2035

Table 4.14 GHG emissions from the conventional and organic rice fields in the northeast of Thailand according to each scenario for 2019, 2025, 2030 and 2035

Year	GHG Emission (Mt CO2eq yr^{-1})			
	BAU	Scenario 2	Scenario 3	Scenario 4
2019	96.155	96.155	96.155	96.155
2025	92.712	92.838	93.233	93.257
2030	94.149	94.380	95.222	97.663
2035	107.353	107.810	109.536	112.094

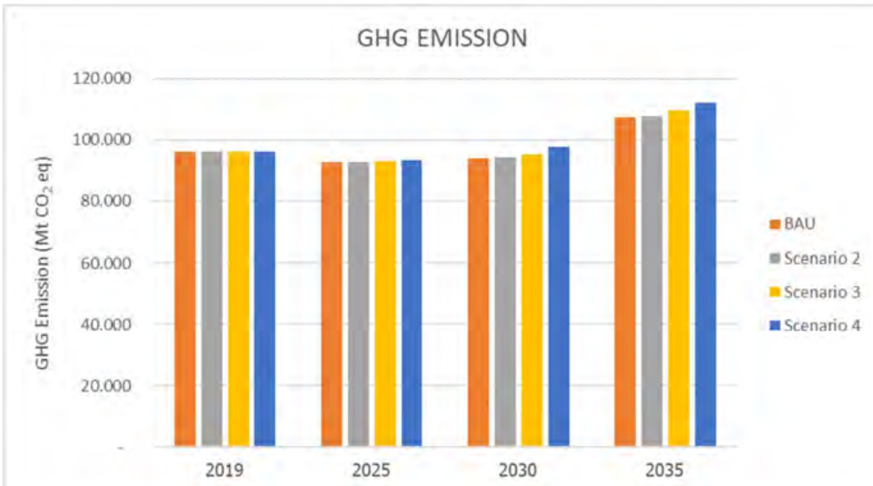


Figure 4.39 Annual GHG emissions (CH_4 and N_2O) from rice field cultivation (conventional and organic fields) in Northeast of Thailand in 2019, 2025, 2030, and 2035

Although the scenario without an action plan (BAU) yields less CH_4 emission, BAU provides more N_2O emissions from the chemical fertilizer. In addition, BAU contributes to the less enhancement of SOC due to less organic amendment application. SOC has been a significant source of atmospheric CO_2. These CO_2 emissions from soil can be offset by storing C in soil as SOC and protecting SOC with a long turnover period (Lal, 2004). Scenarios with action plan (Scenario 2, 3, and 4) provide more SOC and generate more CH_4 than BAU. However, the increase of CH_4 emissions from Scenario 2, 3, and 4 can be mitigated by the water management in the field.

3.3 Post-harvest GHG from rice residual burning

The GHG inventory are estimated including changes in biomass and soil carbon stocks, CH_4 emissions from rice cultivation and from direct and indirect N_2O emissions from soils. The DNDC model is used for inventory calculations. However, the DNDC software package does not cover a burning process that releases both GHG as well as particulate matter (PM) that significantly impact environment and human health.

3.3.1 Method for assessing emissions (both GHG and air pollution) from rice residue burning

For the greenhouse gas emission and air pollution from burning of rice residues in paddy fields, the Carbon monoxide (CO), Carbon dioxide (CO_2), Methane (CH_4), Nitrogen oxides (NO_x), Sulfur dioxide (SO_2), Black carbon (BC), Organic carbon (OC), and two sizes of particulate matter (PM10, and PM2.5) were estimated on the basis of the available literature on the emission of air pollutants from the study of emission of air pollutants from rice residue open burning in Thailand, 2018 (Junpen, et al., 2018). In this analysis, calculations of emissions from burning are only carried out for conventional paddy fields areas, as burning residues is not a permitted practice in the organic rice system. The relevant air pollution emissions are estimated by the formula:

$$E_{sti} = EF_i \times M_{st} \times 10^{-3}$$

where E_i is emission of air pollutant i (tons).

M is the mass of burned dry matter (tons of dry matter).

EF_i is the emission factor of the air pollutant i (grams per kilogram of burned dry matter).

s, t are scenario and year of the study (year).

A number of studies have measured the emission factors. This section of the study transfers selected values from Junpen, et al., (2018), based on nine types of greenhouse gas and air pollution emissions. The value of selected emission factors is shown in Table 4.15.

Table 4.15 Value of emission factors

Gases and particulate matter	Emission factor (EF) (gram per kilogram of burned dry matter)
CO2	1177
CO	93
CH4	9.6
NOx	0.49
SO2	0.51
BC	0.53
OC	3.1
PM2.5	8.3
PM10	9.4

Source: Junpen, et al., (2018)

The mass of burned dry matter was estimated based on Intergovernmental Panel on Climate Change (IPCC) guidelines for national Greenhouse Gas Inventories (Junpen, et al., 2018).

$$M_{st} = \alpha \times RRB_{st}$$

where RRB is quantity of rice residue in the burned field (tons of dry matter)

α is the combustion factor (unitless).

s, t are scenario and year of the study (year).

The combustion factor was studied by Cheewaphongphan and Garivait (2013) based on field experiments to show the fraction of burned rice residue combusted by fire distinguishing each region of Thailand. The average combustion factor in the northeast is 0.52, while the average for the whole country is 0.34. The quantity of rice residue in the burned field, RRB, is estimated by the fraction of rice residue subjected to open burning, FB, and the amount of residue, straw and stubble, generated in the field, RRG. Meanwhile the amount of residue in the field is estimated by burn area, HA, and the density of residue in that area, RD as follows:

$$RRB_{st} = (RRG_t \times FB)$$

$$RRG_{st} = (HA_{st} \times RD_t)$$

where FB is the fraction of rice residues subject to open burning (unitless).

RRG is the amount of rice residues generated in the field (tons).

HA is the rice harvest area in the study year (hectares).

RD is average amount of rice residue density per unit area, biomass load (tons per hectare).

s, t are scenario and year of the study (year).

The rice harvest area, HA, is estimated by the conventional rice area based on four scenarios. For the first Scenario, BAU, it is assumed that 97% of the rice area in northeast is conventional rice, and would be potentially subject to burning, while in Scenario 4, the transformational change towards sustainability scenario, only 13% of the rice area in northeast will be considered as area subject to rice residue burning.

The rice residue density, RD, for Khao Dawk Mali 105 is reported to be about 4.80 tonnes per hectare (Cheewaphongphan et al., 2018). Meanwhile throughout the whole country, different rice varieties range from 4.18 to 8.02 tonnes per hectare.

The fraction of rice residues subject to open burning studied in 2015/2016, surveyed from 6 provinces in northeast Thailand, showed that in the rain-fed fields, the fraction of rice residues subject to open burning was about 21 percent of all rice residue in the field (Cheewaphongphan et al., 2018).

The result of the calculation was determined step by step. Firstly, the conventional rice area from 2019 to 2035 in each scenario was calculated by subtracting the projected organic area from the total rice area of 5,854,336 hectares. Then, the amount of rice residue generated in the field, RRG, was calculated by multiplying the area by the average rice residue density, RD, which is assumed to be 4.80 tons per ha. After that, the quantity of rice residue in the burned field, RRB, according to the fraction burned, FB, which was assessed to be 21 percent. Next, the mass of burned dry matter, M, was computed by multiplying by the average combustion factor for the Northeast, α, or 0.52 (Junpen, et al., 2018). Finally, the emissions of each air pollutant, E, in each year of the four scenarios were calculated by multiplying the kilograms of burned dry matter by the emission factors, EF, set out above. The results of this analysis are presented in Table 4.16.

The amount of rice residues generated in the field, RRG, in this section of our study was focused only on the conventional rice area, due to the fact that burning residues in the field are prohibited in the organic practice. The BAU, having only 0.17 million ha of organic rice in 2035, would see a reduction from 27.6 to 27.2 million tons of residue from conventional rice fields from 2019 to 2035. Meanwhile, scenario four projects a significant reduction in the amount of rice residues generated from conventional fields to 3.5 million tons due to the transfer from conventional rice to organic rice. Analysis from Junpen et al (2018) showed that there were about 61.87 million tons of RRG for the whole country and 31.14 million tons in northeast in 2018.

Table 4.16 Amount of rice residues generated (RRG) from conventional rice fields

Years	RRG						
	BAU	Scenario 2		Scenario 3		Scenario 4	
		Million tons	% change	Million tons	% change	Million tons	% change
2019	27.65	27.653	0%	27.653	0%	27.653	0%
2025	27.27	26.565	-3%	24.261	-11%	24.119	-12%
2030	27.27	25.797	-5%	20.421	-25%	3.524	-87%
2035	27.27	25.029	-8%	16.581	-39%	3.524	-87%

Note: Percent change is compared to BAU

Next, the quantity of rice residues subjected to open burning, RRB, and the mass of burned dry matter, M, were estimated. The results presented in Table 4.17 and 4.18 show that RRB was about 5.81 million tons in 2019 and varied from 5.72 to 0.74 million tons in 2035 in BAU and scenario 4. Meanwhile, the mass of burned dry matter, calculated by using an average combustion factor, α, of 0.52, varied from 2.98 to 0.39 million tons in 2035. The previous study was showed about 5.82 and 3 million tons of RRB and M respectively (Junpen, et al., 2018).

Table 4.17 Quantity of Rice residues subjected to open burning (RRB)

Years	RRB						
	BAU	Scenario 2		Scenario 3		Scenario 4	
		Million tons	% change	Million tons	% change	Million tons	% change
2019	5.807	5.807	0%	5.807	0%	5.807	0%
2025	5.727	5.579	-3%	5.095	-11%	5.065	-12%
2030	5.727	5.417	-5%	4.288	-25%	0.74	-87%
2035	5.727	5.256	-8%	3.482	-39%	0.74	-87%

Note: Percent change is compared to BAU

Table 4.18 Mass of burned dry matter

Years	M						
	BAU	Scenario 2		Scenario 3		Scenario 4	
		Million tons	% change	Million tons	% change	Million tons	% change
2019	3.02	3.02	0%	3.02	0%	3.02	0%
2025	2.978	2.901	-3%	2.649	-11%	2.634	-12%
2030	2.978	2.817	-5%	2.23	-25%	0.385	-87%
2035	2.978	2.733	-8%	1.811	-39%	0.385	-87%

Note: Percent change is compared to BAU

Finally, the emission of air pollutants, E_i, were calculated based on the emission factor presented earlier in Table 4.18. Tables 4.19 – 4.22 show the amount of air pollution generated in each scenario from 2020 to 2035. The results show that the greatest amount of air pollution is from CO2. NOx, SO2, and BC are small amounts. The emissions of PM2.5 are in direct correlation with PM10.

Table 4.19 Projected emissions of each air pollutant (tons) due to rice residue burning in the northeast of Thailand, BAU scenario

Year	CO2	CO	CH4	NOx	SO2	BC	OC	PM2.5	PM10
2020	3,555,568	280,941	29,000	1,480	1,541	1,601	9,365	25,073	28,396
2025	3,505,006	276,946	28,588	1,459	1,519	1,578	9,232	24,717	27,992
2030	3,505,006	276,946	28,588	1,459	1,519	1,578	9,232	24,717	27,992
2035	3,505,006	276,946	28,588	1,459	1,519	1,578	9,232	24,717	27,992

Table 4.20 Projected emissions of each air pollutant (tons) due to rice residue burning in the northeast of Thailand, Scenario 2

Year	CO2	CO	CH4	NOx	SO2	BC	OC	PM2.5	PM10
2020	3,530,810	278,985	28,798	1,470	1,530	1,590	9,300	24,899	28,198
2025	3,414,333	269,782	27,848	1,421	1,479	1,537	8,993	24,077	27,268
2030	3,315,623	261,982	27,043	1,380	1,437	1,493	8,733	23,381	26,480
2035	3,216,913	254,183	26,238	1,339	1,394	1,449	8,473	22,685	25,692

Table 4.21 Projected emissions of each air pollutant (tons) due to rice residue burning in the northeast of Thailand, Scenario 3

Year	CO2	CO	CH4	NOx	SO2	BC	OC	PM2.5	PM10
2020	3,530,810	278,985	28,798	1,470	1,530	1,590	9,300	24,899	28,198
2025	3,118,203	246,383	25,433	1,298	1,351	1,404	8,213	21,989	24,903
2030	2,624,654	207,386	21,408	1,093	1,137	1,182	6,913	18,509	20,962
2035	2,131,105	168,388	17,382	887	923	960	5,613	15,028	17,020

Table 4.22 Projected emissions of each air pollutant (tons) due to rice residue burning in the northeast of Thailand, Scenario 4

Year	CO2	CO	CH4	NOx	SO2	BC	OC	PM2.5	PM10
2020	3,528,856	278,831	28,783	1,469	1,529	1,589	9,294	24,885	28,183
2025	3,100,035	244,948	25,285	1,291	1,343	1,396	8,165	21,861	24,758
2030	452,944	35,789	3,694	189	196	204	1,193	3,194	3,617
2035	452,944	35,789	3,694	189	196	204	1,193	3,194	3,617

Junpen, et al. (2018) ranked the 20 provinces in the Northeast that generated air pollution from rice residue burning in 2018. Their results are presented here in Table 4.23. Roi Et, Khon Kaen, Nakhon Ratchasima, Sakon Nakhon, and Mahasarakham provinces are the top five emitters of air pollution from rice burning in the Northeast. Note that some provinces, showing large rice cultivation areas, have low emissions Ubon Ratchathani and Sisaket, due to the fact that the data in this paper acquired from satellite capturing big flood areas in these provinces in 2018.

Table 4.23 Ranking of emission value of each air pollutant from rice residue burning in 2018

Province	Total rice area* (1,000 Ha)	The amount of emissions from rice residue burning (ton)**					
		CO2	CO	CH4	NOx	PM2.5	PM10
Roi Et	489.55	450,000	35,530	3,670	187	3,170	3,590
Khon Kaen	370.28	400,000	31,600	3,260	166	2,820	3,190
Nakhon Ratchasima	553.82	336,000	26,510	2,740	140	2,370	2,680
Sakon Nakhon	344.13	302,000	23,830	2,460	126	2,130	2,410
Mahasarakham	329.95	233,000	18,420	1,900	97	1,640	1,860
Buriram	443.08	149,000	11,770	1,220	62	1,050	1,190
Kalasin	235.21	143,000	11,320	1,170	60	1,010	1,150
Yasothon	213.13	126,000	9,940	1,030	52	890	1,010
Chaiyaphum	251.59	124,000	9,830	1,020	52	880	990
Udon Thani	281.53	80,000	6,350	660	33	570	640
Surin	486.76	79,000	6,260	650	33	560	630
Nong Bua Lamphu	104.98	67,000	5,290	550	28	470	540
Ubon Ratchathani	627.94	44,000	3,450	360	18	310	350
Nakhon Phanom	218.91	41,000	3,280	340	17	290	330
Amnaj Charoen	157.50	24,000	1,890	200	10	170	190
Nong Khai	85.54	18,000	1,440	150	8	130	150
Sisaket	481.07	16,000	1,240	130	7	110	130
Mukdahan	78.15	6,000	460	50	2	40	50

Province	Total rice area* (1,000 Ha)	The amount of emissions from rice residue burning (ton)**					
		CO2	CO	CH4	NOx	PM2.5	PM10
Loei	69.84	3,000	270	30	1	20	30
Bueng Kan	77.56	1,000	70	10	0	6	10

Source: * Office of Agricultural Economics (2018), ** Junpen, et al. (2018)

Meanwhile, our results showed that Ubon Ratchathani, Nakhon Ratchasima, Surin, Roi Et, and Si Sa Ket, which are the highest five rice cultivation areas of the region, generate the highest air pollution emission, as presented in table 4.24. However, considering the data of rice area and organic rice area together would show that the provinces with high proportion of organic rice area could release the relatively lower air pollution than others that have similar total rice cultivation areas, such as Roi Et compared to Surin, and Khon Kaen compared to Sakon Nakhon.

Table 4.24 The estimation of air pollution from rice residue burning from 20 province in 2019, racking from rice cultivation area

Province	Total rice area* (1,000 Ha)	Organic rice area** (1,000 Ha)	The amount of emissions from rice residue burning (ton)***					
			CO2	CO	CH4	NOx	PM2.5	PM10
Ubon Ratchathani	733.65	2.67	450,965	35,633	3,678	188	3,180	3,602
Nakhon Ratchasima	617.73	13.20	372,959	29,469	3,042	155	2,630	2,979
Surin	546.35	7.11	332,678	26,286	2,713	138	2,346	2,657
Roi Et	**545.50**	**19.44**	**324,549**	**25,644**	**2,647**	**135**	**2,289**	**2,592**
Si Sa Ket	534.45	1.47	328,813	25,981	2,682	137	2,319	2,626
Buri Ram	501.56	18.01	298,320	23,572	2,433	124	2,104	2,383
Khon Kaen	**400.70**	**37.05**	**224,349**	**17,727**	**1,830**	**93**	**1,582**	**1,792**
Sakon Nakhon	394.47	0.48	243,069	19,206	1,983	101	1,714	1,941
Udon Thani	317.96	1.92	194,974	15,406	1,590	81	1,375	1,557
Maha Sarakham	313.53	5.39	190,105	15,021	1,551	79	1,341	1,518
Chaiyaphum	259.88	9.74	154,323	12,194	1,259	64	1,088	1,232
Nakhon Phanom	259.53	5.81	156,530	12,368	1,277	65	1,104	1,250
Kalasin	241.46	2.73	147,281	11,637	1,201	61	1,039	1,176
Yasothon	239.53	1.29	146,982	11,614	1,199	61	1,036	1,174
Amnat Charoen	183.61	8.53	108,012	8,535	881	45	762	863
Nong Khai	112.65	0.06	69,458	5,488	567	29	490	555
Nong Bua Lam Phu	104.80	0.47	64,365	5,086	525	27	454	514

Province	Total rice area* (1,000 Ha)	Organic rice area** (1,000 Ha)	The amount of emissions from rice residue burning (ton)***					
			CO2	CO	CH4	NOx	PM2.5	PM10
Bueng Kan	90.86	1.95	54,851	4,334	447	23	387	438
Mukdahan	83.80	0.21	51,570	4,075	421	21	364	412
Loei	77.37	0.03	47,711	3,770	389	20	336	381

Source: * Land Development Department, ** Rice Department, *** our calculation

Assessment of GHG emissions from rice residue burning

The GHG emissions from rice stubble burning are calculated based on chapter 2 of 2006 IPCC guidelines for national greenhouse gas inventories, which exclude CO2 in the calculation ((Eggleston, H. S., et al., 2006). To compare the GHGs emission from burning in each scenario, the global warming potential values, GWP, are calculated based on the IPCC's fifth assessment report (AR5). The GWP 100 years value of CH4 and NOx are 28, and 265 respectively. Given that rice residue burning is banned in organic rice fields, a change in patterns of rice cultivation from conventional to organic would reduce air pollution emissions from burning, especially in GHGs, and particulate matter (PM2.5 and PM10) as shown in figures 4.40, 4.41, and 4.42. The GHGs emissions from burning would shrink from 1.2 million tons of CO2e to about 1.09 (91%), 0.72 (60%), and 0.15 (13%) million tons of CO2e in the second, third, and fourth scenarios respectively, relative to BAU.

Figure 4.40 GWP from burning rice residues according to each scenario (million tons of CO2eq)

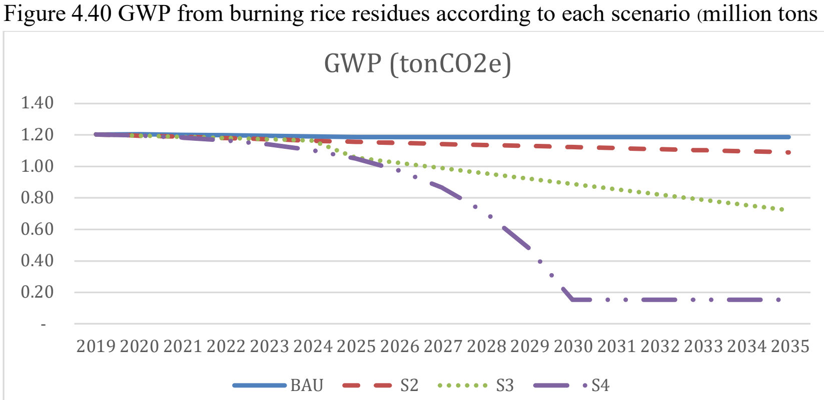


Figure 4.41 Particulate emissions (PM2.5) from burning rice residues in each Scenario (tons) see health analysis section for discussion

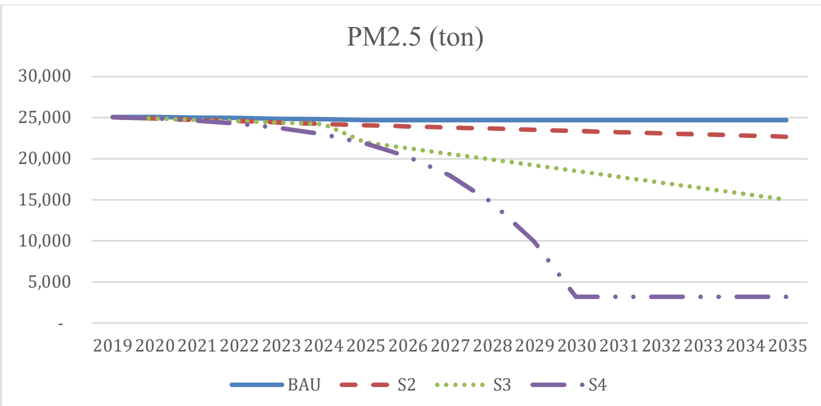
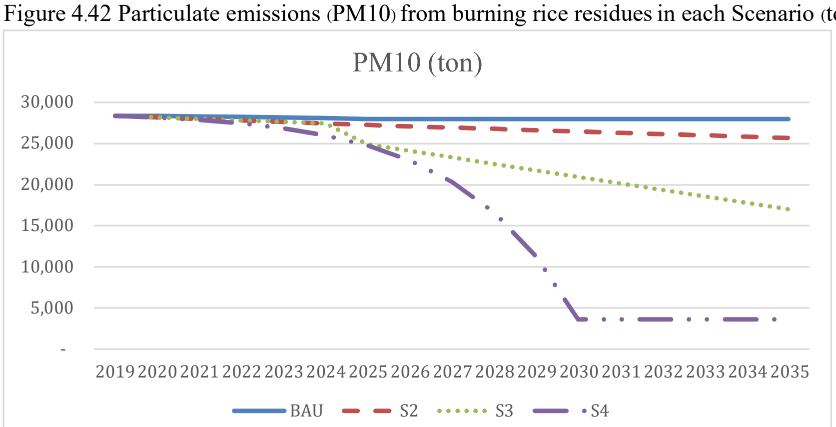
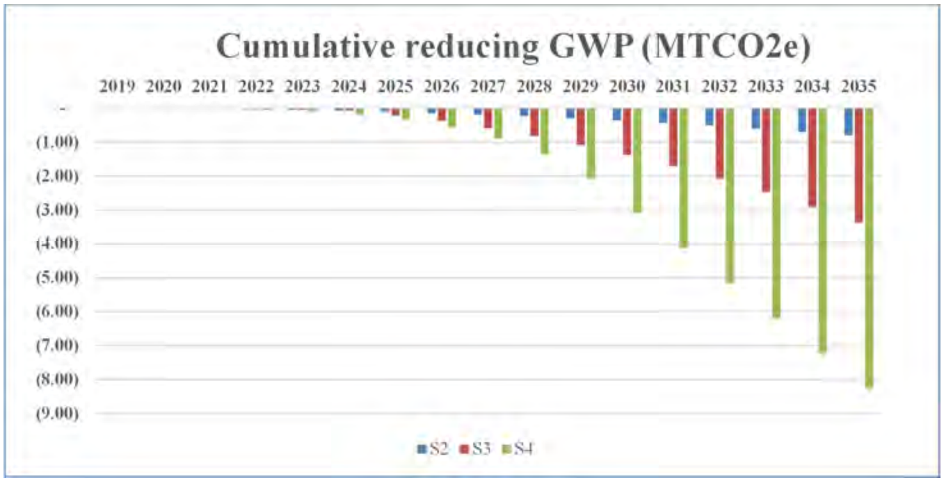


Figure 4.42 Particulate emissions (PM10) from burning rice residues in each Scenario (tons)



The results show that the cumulative reduction of GHGs emission relative to the BAU scenario were 0.79, 3.27 and 8.27 million ton of CO_2eq in the second, third, and fourth scenario, respectively.

Figure 4.43 Cumulative reduction of GHGs (CH4 and NOx) from residue burning in terms of GWP emission relative to BAU scenario (MTCO2eq)



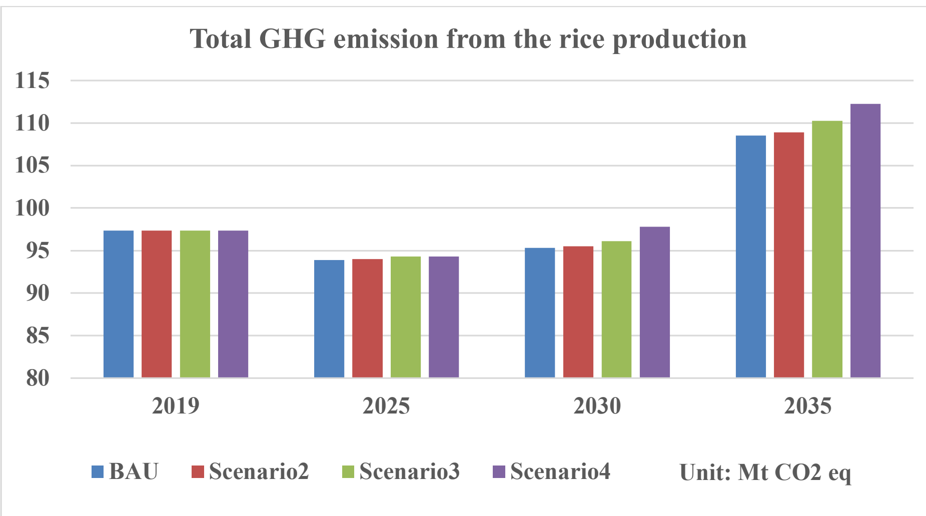
3.4 Net GHG emission from cultivation and post-harvest on each scenario

Concerning overall GHG emissions, the total accumulated emissions in term of GWP, which combine CH4 and NOx emissions from rice cultivation and post-harvest in the rice fields, are calculated together. As seen in the Table 4.25 and Figure 4.44, the highest accumulated GHG emission comes from the Scenario 4 followed by the Scenario 3, the Scenario 2, and the Business as Usual (BAU) scenario, respectively. In the fourth scenario, even if GHG emission could be reduced from rice residual burning, it still provides the highest accumulated GHG emission because it yields the highest accumulated CH4, which is the dominant emission in rice field. CH4 emission from our study presented in similar trend with previous research that collected CH4 from the chamber in conventional and organic rice fields. This study found that CH4 emission from organic rice field tended to be higher than conventional rice field (Pengthamkeerati et al., 2011).

Table 4.25 Total projected accumulated emissions from the conventional and organic rice fields in the northeast of Thailand

Year	Total GHG Emission (Mt CO_2 eq)			
	BAU	Scenario2	Scenario3	Scenario4
2019	97.36	97.36	97.36	97.36
2025	93.90	93.99	94.29	94.31
2030	95.34	95.50	96.11	97.82
2035	108.54	108.90	110.26	112.25

Figure 4.44 Total accumulated GHG emissions (CH_4, NO_x) from the rice fields (conventional and organic fields) in Northeast of Thailand in 2019, 2025, 2030, and 2035



4. Rice yield estimations under different rice field management practices in rainfed systems

The rice yield is influenced by genotypes, managements, environmental conditions (Blanche et al., 2016); therefore, the optimal former conditions are required to improve the yield. Additionally, management is the crucial factor for improving the production when the same rice varieties are planted under the same environment. In this study, the yield from rainfed systems under conventional and organic practices are estimated using the Denitrification-Decomposition (DNDC) model.

In this project, Northeast region were divided into two groups which were the group of upper Northeast provinces and lower Northeast provinces. Khon Kaen, Sakon Nakorn, and Udon Thani were the representative provinces which were in the top three largest harvested area of rice in the upper Northeast group. Ubon Ratchathani, Roi-et, Nakorn Ratchasrima, and Surin were the representative provinces which were in the top four largest harvested area of rice in the lower Northeast group. Additionally, the cumulative harvested area of the representative provinces in each group was more than 50% of the total harvested area of its group. The rice yield of each province was predicted from 2019-2035 based on simulated weather conditions, then the yields in the same group were averaged to represent the yield of upper or lower Northeast groups. Finally, the average yield of upper and lower Northeast group will be used to calculate the total yields both organic and conventional rice.

Yield estimation from this model is based on many factors as follows. First is the climate data. We used future precipitation, minimum, and maximum air temperature over 2019-2035 from RU-CORE. The next factor was soil textures and properties. We used soils data from the Land Development Department (LDD). The third factor is types and amounts of fertilizer applied in rice field. The data from household survey, the government published reports, supplemented data from the Rice Department and the Office of Agricultural Economics, Ministry of Agriculture and Cooperatives were used to set the crop calendar, field management practices, and calculate the average amounts of plant nutrients applied into the field for conventional practice. For organic rice practice, we used an average amount of cow manure applied by organic farmers from our household survey to calculate amounts of plant nutrients applied into the organic rice field. Both rice field management practices have the same soil and water preparation (same tillage practices for example), provided by the research of Cha-un et al. (2021). Details of each variable is presented in table 4.11.

Figure 4.45 shows the projected annual rice yield over 2019-2035 under different rice field management practices. Considering the conventional rice fields, the estimated average yield from the conventional rice is 2.33 tons per ha per year (range from 2.16 to 2.82 tons per ha per year). Conversely, in organic rice fields, the estimated average yield from the organic rice is 2.27 tons per ha per year (range from 1.98 to 2.73 tons per ha per year). The yield from both practices is similar to the office of agricultural economics (OAE) data[54] on average rice yield from 2011 to 2019, which was 2.26 tons per ha. Comparing between the practices, the yield of organic practice is slightly lower than conventional practice, approximately 0.06 tons per ha per year. Comparing between the fertilizer applied to conventional and organic rice fields, inorganic N input is applied more in conventional rice fields than in organic rice fields. A high amount of inorganic N results in the increase of yields. Although the optimal amount of inorganic N may be added to the field in the cultivation process, the inorganic N can be lost from the soil through runoff or leaching that can cause the lack of the nutrients for plant growth resulting in yield reduction.

[54]https://www.oae.go.th/view/1/%E0%B8%95%E0%B8%B2%E0%B8%A3%E0%B8%B2%E0%B8%87%E0%B9%81%E0%B8%AA%E0%B8%94%E0%B8%87%E0%B8%A3%E0%B8%B2%E0%B8%A2%E0%B8%A5%E0%B8%B0%E0%B9%80%E0%B8%AD%E0%B8%B5%E0%B8%A2%E0%B8%94%E0%B8%82%E0%B9%89%E0%B8%B2%E0%B8%A7%E0%B8%99%E0%B8%B2%E0%B8%9B%E0%B8%B5/TH-TH#tab70610

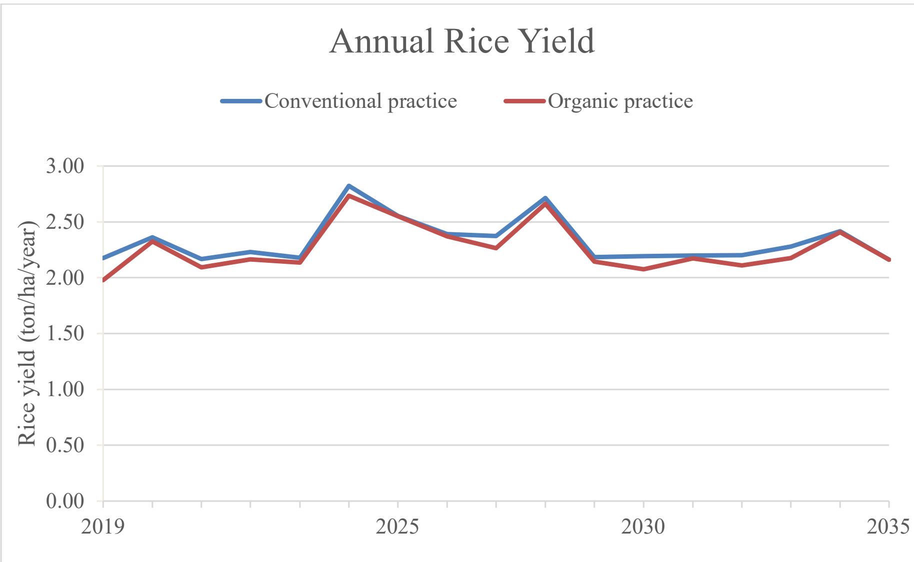


Figure 4.45 Projected annual rice yields from conventional and organic rice field management practice over 2019-2035

4.1 Rice Production prediction based on scenario analysis

As described earlier in this report, four scenarios have been put forward for assessment including: 1) Business as Usual (BAU) Scenario, 2) One million rai organic rice promotion continued, 3) Enhanced organic rice promotion, and 4) Transformational change towards sustainability. Results from these assessments are summarized for the years 2019, 2025, 2030, and 2035.

Table 4.26 and Figure 4.46 presents the projected annual rice productions from the conventional and organic rice fields in the northeast of Thailand according to each scenario. Based on the results of the model for the whole region, average yields from organic rice (2.19 tons per ha per year) is slightly lower than from conventional rice (2.27 tons per ha per year). This may be due to the fact that fewer nutrients are applied into organic rice field than conventional rice (Table 4.11). Therefore, the increase in area of organic rice fields, replacing conventional rice fields, projected by the scenarios put forward, without nutrient management could cause a reduction of total rice production in certain years such as annual rice production in 2030 (Figure 4.46). When we look forward to total rice production in each scenario, all scenario trend to presents the similar rice production relative to others in each of the selected years. Comparing Scenario 3 and 4, rice production in 2030 is the lowest, since the high level of the predicted precipitation caused the loss of nutrients by leaching and runoff resulting in the reduction of rice production. According to the loss of nutrients, the production in organic rice fields can be affected more than in conventional rice fields because the low nutrient input in the organic practice relative to the conventional practice. To produce higher yields in organic rice fields, essential plant nutrients should be provided in an appropriate amount which meets plant requirement. In organic rice fields, the plant nutrients from organic amendments are lower than in conventional rice fields causing the lower yield from organic rice fields in these areas. This could be addressed by adding more organic amendments to the field to increase plant nutrients. However, if an excess of nutrients are added to the fields, they will increase the substrate for producing GHG emissions. In this case, water management can help to decrease CH_4 emission which is the dominant emission from the rice field. Cha-un et al. (2021) simulate the long-term effects of fertilizer and water management on grain yield and methane emission of paddy rice in Thailand. The results presented that the application of chemical fertilizer and chemical fertilizer combined with manure provided higher grain yields than the treatment of manure application. Also, methane emissions increased by 19.1-127.8% were found in the treatment of chemical fertilizer and chemical fertilizer combined with manure applications. Comparing among the water treatments, alternate wet and dry had a high potential to maintain rice grain yield and reduce methane emissions relative to continuous flooding and mid-season drainage (Cha-un et al., 2021). Pengthamkeerati et al. (2011) presented that the conventional rice field emitted methane higher than the organic rice field. Also, the organic rice field with continuous flooding yielded methane emissions more than the organic rice field with mid-season drainage.

Table 4.26 Total projected annual rice production from rice fields in the northeast of Thailand in each scenario

Year	Annual Rice Production (Mt yr^{-1})											
	BAU			Scenario 2			Scenario 3			Scenario 4		
	Con	Org	Total	Con	Org	Total	Con	Org	Total	Con	Org	Total
2019	14.26	0.25	14.51	14.26	0.25	14.51	14.26	0.25	14.51	14.26	0.25	14.51
2025	16.06	0.59	16.65	15.46	1.09	16.65	13.93	2.72	16.65	13.83	2.82	16.65
2030	14.09	0.49	14.58	13.16	1.36	14.52	9.75	4.53	14.28	0.14	13.59	13.73
2035	13.91	0.52	14.43	12.51	1.92	14.43	7.23	7.20	14.43	0.14	14.30	14.44

Note: Con = rice production from conventional practice; Org = rice production from organic practice; and Total = rice production from the whole region, the northeast of Thailand

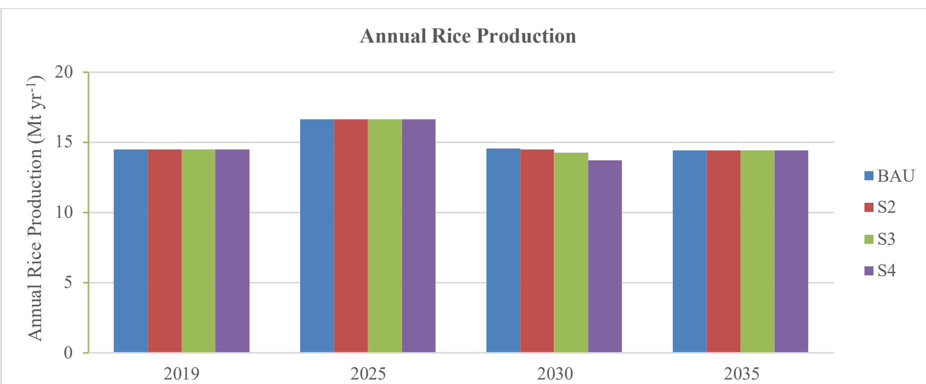


Figure 4.46 Bar chart showing projected annual rice production in each scenario from the rice fields in Northeast of Thailand in 2019, 2025, 2030, and 2035

5. Health impacts analysis

In this section, the study seeks to measure health impacts of conventional and organic rice practices on farmers[55]. The health risks arising from rice production in this study include the potential health risks to farmers associated with the use and misuse 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. Note that the use of pesticides and air pollution from rice straw burning after harvesting are prohibited for organic rice practice. Therefore, the health impacts from pesticides and air pollution due to rice straw burning only come from conventional rice practice.

5.1 Use and misuse of agricultural pesticides applied to rice production

One of the differences between conventional and organic rice practices is the application of pesticides in rice cultivation. Pesticide is prohibited to be used in organic rice practice, while it is widely used in conventional rice practice. From this situation, we try to identify the effects of pesticide on farmers' health and to measure them in the form of monetary value. We use data from two sources. The first one is from the household survey that asked organic and conventional rice farmers to identify their symptoms and sickness from pesticide poisoning. The second source of data is from choice experiment survey, which is outlined in detail in Appendix 4. Both types of farmers were asked to trade-off between a change in the fatality risk due to exposure to pesticides and a change in the price of rice. This trade-off information from choice experiment survey provided by both types of farmers can be converted to a monetary value by applying a value of statistical life (VSL) analysis to find the marginal cost of enhancing safety or the value placed by farmers on the reduction of fatality risk from pesticide poisoning.

We start from the household survey. From 415 conventional farmers who answered to our questionnaire, nine of them, or about 2.17 percent, reported symptoms and illnesses perceived as due to pesticides applied in rice fields in the last cropping season. All nine farmers reported minor symptoms such as skin irritation, nausea, and headache. Among them, six farmers reported that they needed to see doctors to get medical treatments. The average cost of medical treatment reported by this group of farmers is 390 Baht (about $13) per individual for the last cropping

[55] We plan to conduct consumer survey to identify health concerns from consumers. The survey will be conducted after the Covid-19 restrictions are eased.

season. The average medical treatment cost observed from household survey would be the minimum measurement of pesticides' impacts on farmers' health. This is because the impacts of pesticides comprise not only symptoms and illnesses in the short-run, but also exposure to pesticides for long period of time (Dhananjayan and Ravichandran, 2018). However, to calculate the latter requires rich data that at least tracks individuals' pesticides exposure, illnesses, and death information for significant period of time (Tawatsin et al.,2015). This type of data, to our knowledge, is not yet available in Thailand.

By contrast, for 437 organic rice farmers that responded to our survey, none of them reported any illnesses caused by pesticide poisoning applied in rice fields. Even though the different number of farmers affected by pesticides between conventional and organic farmers may not be many from our survey, it is significant in context, zero case versus nine cases. Since there are about 4.30 million rice farming households and most are conventional rice farmers, following incident rate from our survey there would be about at least 90,000 conventional farmers whose health affected by pesticide poisoning every year and the health cost would be at least about 35.10 million Baht (about 1.17 million USD)[56].

The health cost calculated from survey data is the minimum health cost relied on visible cost of treatment, which may not reflect all benefits gained from treatment and health risk reduction, especially when such benefits may not be traded explicitly in the market (Mahasuweerachai, 2013). To capture these unobservable impacts of pesticides on farmers' health, we applied a choice experiment survey to find the VSL from reducing the risk of fatality by pesticide poisoning in rice farming. The choice experiment survey could directly elicit values of risk reduction from farmers' preferences. For more details of choice experiment design and estimation results please see Appendix 4.

From the choice experiment estimates, the VSL from reducing fatality risk from pesticide poisoning by 0.0001 percent (1 out 10,000) is between 14,169.43-16,060.35 Baht (about $472-$535) per household, which is on average about 19-22 percent of income each rice farmer household receives from selling rice each year.

Note that the VSL calculated from choice experiment could be seen as the upper bound value placed by farmers on reducing fatality risk caused by pesticide poisoning, while the value

[56] We assumed that only one member from each household is affected by pesticide poisoning. The number of 90,000 conventional farmers sickened from pesticide is therefore the minimum number.

calculated from household survey may be seen as minimum bound value because it does not obtain the invisible and long run effects of pesticides that may cause chronic diseases affected liver function and neurological system, which result into varieties of losses such as loss of income due to inability to work, long-term medical costs, and loss of life.

5.2 Economic Health Cost caused by air pollution from rice straw burning (PM2.5)

The various diseases caused by exposure to air polluted with fine particulate matter (PM2.5) can be related to a range of pollutants and pollution sources. This section of the report applies the methodology from a study that aims to assess the impacts of PM2.5 on public health across the country[57]. The negative health impacts affecting human wellbeing in premature mortality was evaluated as means to represent economic losses. According to He et al. (2019), PM2.5 is an essential component for air pollution and sensitive to measurement near a ground surface due to wind speed. Satellite data is a reliable source to extract information on PM2.5 concentrations. The equation below shows the relationship between the determinants of PM2.5, including the sulfate, organic carbon, black carbon, dust, and sea salt, which are the primary ambient pollutant particles at 2.5 microns (He et al., 2019).

$$PM_{2.5} = 1.375 \times SO_4 + 1.6 \times OC + BC + Dust_{2.5} + SS_{2.5}$$

Satellites retrieve data on the annual concentration of these pollutants, in microgrammes per m^3, across Thailand's provinces. In the NE region, organic carbon and dust are found in the highest concentrations relative to other particulate matter. Sea salt has the lowest concentration.

The PM2.5 health effect is assessed based on the pollutant concentration in an exposure-response function. Under this approach, the source and precise chemical composition of fine particles is of secondary concern to the absolute quantity of inhaled pollution; as a result, health impacts from ambient air can be aggregated and analyzed along a unified exposure-response curve.

Health impacts can be classified into two forms depending on the health endpoint: mortality and morbidity. It refers to the percentage change in mortality or morbidity rates of health endpoints

[57] "The spatial spillovers effects of PM2.5 and impact on public health cost: new evidence from Thailand (Saengavut, Jirasatthumb, and Marks, 2020 Manuscript)

per 10µg/m^3. The health impacts of PM2.5 in this study were estimated in premortality caused by respiratory system disease. On the basis of epidemiological studies, air pollution with a concentration of ten microgrammes of PM2.5 have been associated with the increased incidence of mortality from cardiovascular, respiratory, lung cancer, and all-cause mortality. In the final step, the exposure risk to PM2.5 is used for evaluating the economic loss.

The Amended Human Capital (AHC) approach is based on the concept of the loss of entire society productivity because of individual absence from work and adjusted with GDP per capita. The Value of a Statistical Life (VSL) analysis is complementary with AHC as another approach for monetary valuation of health impacts. AHC and VSL methods are considered the lower bound and upper bounds of estimating the health costs. The two methods measure the use-value of related costs, but do not account for non-use value such as quality of life and experience of pain. VSL is estimated from eliciting the willingness to pay for a marginal reduction of fatal risk (Hammit, 2000) and converted with disposal income. Other valuation methods in quantifying health impact, namely Quality Adjusted Life Years (QALY) are suitable for the long-term illness and disability to reflect individual's wellbeing, but it has ethical and context limitations (Pettitt, et al.,2016). AHC is commonly applied in epidemiology and economic literature in evaluating the human capital value loss caused by air pollution, especially fine particulate matter in China (Huang et al., 2012; Yin et al.,2015; Yin et al.,2017). Information on potential disease caused by PM2.5 are derived from Thai research projects (Jenwitheesuk, K., Peansukwech, U., & Jenwitheesuk, K. (2020) and previous evidence (Yin et al.,2015) based on the ICD-10[58] reports. In this study, the health impacts caused by PM2.5 from rice burning focuses on premature mortality caused by PM2.5 using the AHC approach. The analysis is limited by the available information on long-term disease morbidity such as chronic bronchitis.

The Amended Human Capital per case is expressed in the equation below. It was calculated based on a Gross Provincial Product (GPP) of province j in year k (GPP_{j0})[59], α is the per capita GPP growth rate, and γ is a social discount rate[60], t is the average number of life-years lost due to PM2.5, which is assumed to be 10 years (Yang et al., 2015).

[58] The 10th version of the International Classification of Diseases.
[59] A based year is 2012. The statistic of GPP applied from the Office of the National Economic and Social Development Council in 2018
[60] 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

$$AHC = GPP_{j0} \cdot \sum_{k=1}^{t} \frac{(1+\alpha)^k}{(1+\gamma)^k} \quad (2)$$

Finally, the value of economic losses from health impacts for each case is assessed from exposure to all ambients (Wang et al., 2020). The AHC model assumes that the human capital value is considered from the standpoint of the entire society, without taking individual characteristics into account (Hou et al.,2012).

In this section, the recent Thai evidence on economic damage related to exposure to air pollution (particulate matter) is introduced to discuss the consistency of our results. To the best of knowledge, this study is the most updated and relevant evidence in Thailand. Attavanich (2019) estimates the economic cost of air pollution and calculate health cost by province. In that study, the author applied the concept of subjective wellbeing (SWB)[61], reflecting an average household's willingness to pay for the benefit of reducing a unit of air pollution (PM10). The SWB measures household's life satisfaction (happiness score) estimated as a function of income and environment. The life satisfaction function controls for household characteristics (age, gender, education, marital status, employment), health condition perception, weather conditions, and pollutants (PM_{10}, NO_2, O_3, CO, and SO_2). The regression estimates are applied to estimate the marginal willingness to pay for each pollutant, and it presents the provincial economic cost of air pollution, aggregating to the social cost.

The estimated economic cost in Attavanich's study is higher than that determined using the AHC method in the current study. The author estimates the social cost of air pollution on the principle of subjective wellbeing (Levison, 2012), which assumes that environment quality is a factor determining the individual's life satisfaction or happiness. The life satisfaction can be affected by income and other social factors such as family life, social life, and occupation. The authors applied data of subjective wellbeing collected by the National Statistical Office and Thai Health Promotion Foundation. Unlike the present study, the cost assessment of premortality due to PM2.5 is cause-specific. The results of the two studies are illustrated in Figure 4.47. The green line (top graph) indicates the social cost measured by SWB, and the blue line (bottom graph)

developing countries (Medalla, 2014). In the context of health impact, the parameters values of the social discount rate are 8%.

[61] Subjective well-being or happiness is used to place a monetary value from survey data on the stated "self's report levels of "well-being" or life satisfactions (Levinson 2012). The determinations of life satisfaction include income and environmental quality.

indicates the health impact cost assessed using the AHC method. Both studies present the same top four provinces with the highest economic cost, namely Nakorn Ratchasima, Khon Kaen, Udon Thani, and Ubon Ratchathani. Although the order of the provinces with the lowest economic cost is not precisely matched, the result indicates that the provinces are in the same geographical region, Amnat Charoen, Mukdahan, Yasothon, Nong Bua Lamphu, and Bueng Kan. So, we can confirm and apply the results using AHC as a lower bound estimation of health impact caused by PM2.5.

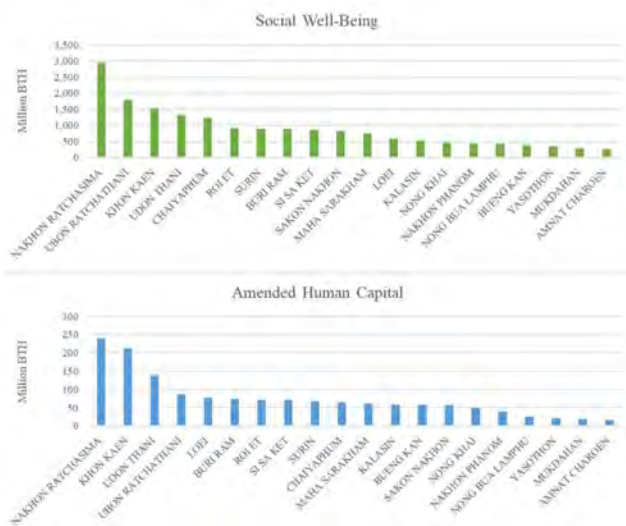


Figure 4.47 Results of economic cost comparisons between SWB and AHC methods

Specifically, the estimate of economic loss in the three selected provinces of the study area is shown in Table 4.27 below. The health cost estimation further presents a percentage in the rice production costs retrieved from a household survey. It is essential to adjust the population in a similar group between health cost and production cost. The average cost[62] of rice production at all stages (per rai) is used as sample values, multiplied by the number of farmer households in each province (DOAE). Then, a percentage of health cost is proportional to the production cost. The rice farmers in Khon Kaen have five dollars in health cost for every 100 USD of rice production cost. In other words, each 100 USD investment in conventional farming will cause the health cost to increase by 5 dollars.

[62] The average production costs (per rai per household) is for Surin, Khon Kaen, and Buriram, respectively.

Table 4.27 The estimated health cost of exposure to air pollution from rice burning based on AHC approach

Province	PM2.5 (µg/m^3)	Health cost		Percentage in rice production cost (%)
		(Baht/Year)	(USD/Year)	
Surin	22.201	91,829,000	3,060,000.97	1.651
KhonKaen	22.495	239,748,000	7,991,000.60	5.052
Buriram	21.614	71,271,000	2,375,000.7	1.437

Note: 1USD = 30 Baht

The two figures below present the spatial distribution of concentration of PM2.5, based on annual data from satellite observation, and economic losses by province is assessed based on AHC method. The yellow points represent the location of the paddy fields (both organic and conventional rice practices). The exposure to PM2.5 is clustered in the northern part of the region and scattered toward southwest provinces. Surin has a relatively high mean level of PM2.5 in the southern part, while the eastern part of the region has lower levels. However, the distribution of PM2.5 and economic cost is not always consistent between provinces. (Some certain provinces with high PM2.5 may have low economic costs) such as Ubon Ratchatani, Nakhon Phanom, and Bueng Karn. The reason is that although PM2.5 is one environmental factor used to estimate the economic cost, other potential variables influence the health cost (income, the population are exposed to the risk, and other socio-economic factors (Sun & Wang, 2021).

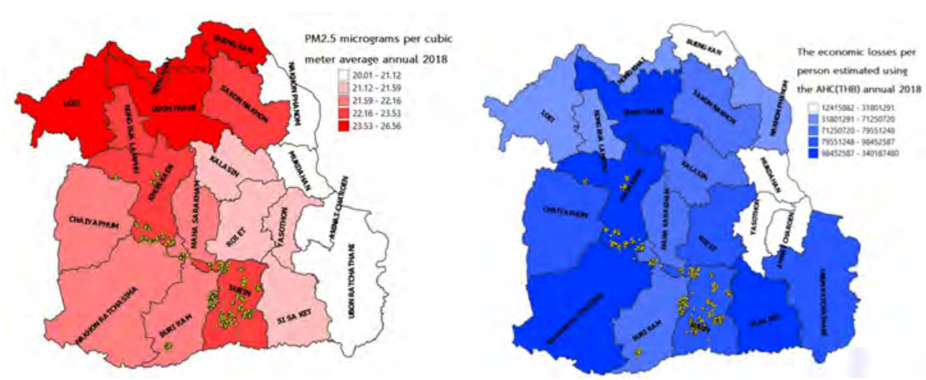


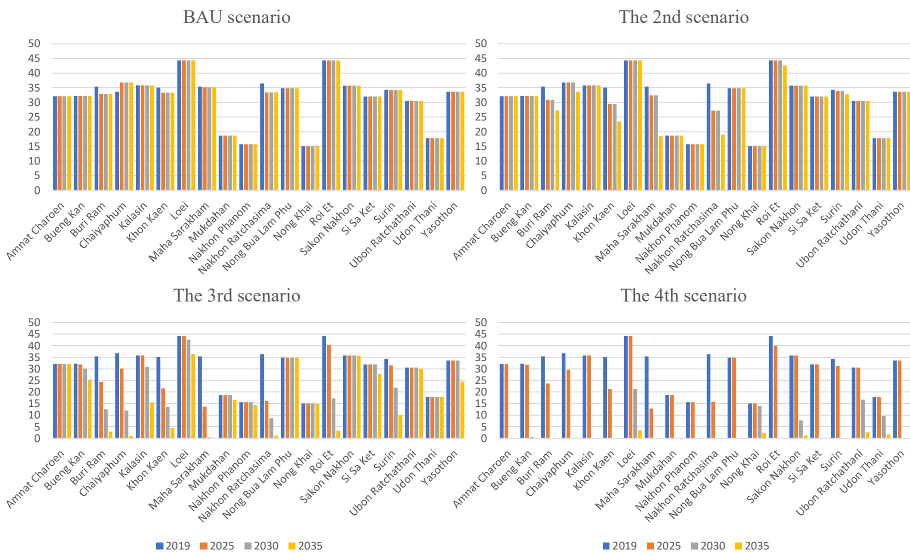
Figure 4.48 Spatial distribution of levels of PM2.5 concentration and provincial economic losses assessed by AHC method, Northeastern Thailand.

5.2.1 Health cost caused by PM2.5 analysis according to scenarios

This section presents an analysis of the health cost association of PM2.5 according to policy scenarios. According to organic rice expansion scenarios described in earlier sections of this report, the organic rice area is projected to expand according to different policy targets, while the conventional rice area decreases correspondingly over the periods outlined. Since burning rice straw is prohibited in organic rice practice, it is assumed that burning is to be found only in conventional rice cultivation areas, particularly before and after rice production. Therefore, we expect that health costs associated with high levels of PM2.5 would decrease as the conventional rice area declines. In this section, organic rice areas and other sources of agricultural residue burning are excluded, such that the conventional rice area is considered the primary emission source of PM2.5.

In order to evaluate the health costs associated with the emissions of PM2.5 from rice straw burning, it is necessary to convert the quantity of PM 2.5 emissions (see GHG emissions section above) into a value of concentration of PM2.5 in the atmosphere. However, there is no reference method for converting quantity to concentration. We have therefore calculated a relative concentration value based on the change from conventional to organic cultivation area, according to the four scenarios, and reported these for the selected years in each case. The conversion method in this study is presented in the appendix 5. The results, presented by figure 4.49, show that average PM2.5 concentration is around 30 micrograms per cubic meter in BAU scenario. However, the PM2.5 concentration dramatically decreases in 2030 in the third and fourth scenarios. It should be noted that these estimates of PM2.5 emissions relate only to rice production, and not to PM2.5 emitted from other agricultural sources, such as sugarcane cultivation. Thus, under the scenarios, the reductions indicated are directly correlated with changes in rice cultivation practices.

Figure 4.49 The prediction of PM2.5 concentration for each scenario



The predictions of PM2.5 concentrations were then further applied to assess human health impacts. The evaluation considers the change in incidence of particular health impacts per μg/m^3 increment in levels of PM2.5 concentration.

In this study, the health impact *i* under a level of PM2.5 was identified to avoid double counting of health endpoint, specifically, the increasing risk of mortality from all-cause mortality and cause-specific mortality (cardiovascular disease, lung cancer, respiratory disease) (Yin et al., 2017). According to the World Health Organisation (WHO, 2018), PM2.5 concentrations above 10 μg/m^3 are considered as having health effects, and the WHO guideline is applied in our study. To quantify the health impacts across the four future scenarios, the population for each province was projected forward based on 0.28% exponential annual growth rate (Thailand population 1950-2020). It yields a number of cases resulting from PM2.5 pollution. The results shown in Table 4.28 are presented by health impacts. Results for all health impacts are influenced by the difference in population distribution across theses provinces. According to the estimates presented in Table 4.28, a correlation can be seen between those provinces with a large area of conventionally grown rice (Ubon Ratchatani, Nakhon Ratchasima, Surin, and Sri Sa Ket) and higher numbers of people affected by health impacts from exposure to PM2.5. It is noticed that Nakhon Ratchasima, Sakon Nakhon, Si Sa Ket, Surin, and Ubon Ratchathani stand out with the highest health impacts.

Table 4.28 Estimated number of people who have died from causes related to air pollution (PM2.5) in NE Thailand (10µg/m3) (unit: case)

Province	Population (Million people)	All-cause[63] mortality	Cardiovascular mortality	Respiratory mortality	Lung cancer mortality
Nakhon Ratchasima	0.378	391.14	100.42	59.12	123.66
Buri Ram	0.424	226.14	58.07	34.17	71.40
Surin	1.596	189.26	48.61	28.59	59.67
Si Sa Ket	1.137	180.48	46.37	27.25	56.74
Ubon Ratchathani	0.983	214.66	55.17	32.39	67.36
Yasothon	1.803	70.73	18.17	10.68	22.28
Chaiyaphum	0.643	169.89	43.62	25.68	53.73
Amnat Charoen	0.963	46.60	11.97	7.04	14.65
Bueng Kan	0.353	52.57	13.51	7.94	16.53
Nong Bua Lam Phu	0.719	71.04	18.24	10.73	22.41
Khon Kaen	2.649	252.38	64.81	38.13	79.65
Udon Thani	0.513	68.14	17.55	10.25	21.04
Loei	0.522	123.67	31.70	18.73	39.49
Nong Khai	1.305	14.64	3.77	2.20	4.50
Maha Sarakham	1.153	136.71	35.11	20.66	43.17
Roi Et	1.473	251.36	64.44	38.07	80.28
Kalasin	1.397	141.81	36.41	21.43	44.80
Sakon Nakhon	1.878	165.96	42.61	25.08	52.42
Nakhon Phanom	1.587	22.54	5.81	3.39	6.94

To predict the economic cost on health, the gross provincial product (GPP) is calculated based on the growth rate during 2012-2019 (NESDC, 2019). The analysis shows that all-cause mortality was included in the estimate of economic costs due to PM2.5 pollution. Table 4.29 shows the economic cost of heath impact based on the BAU scenario in 2019. The economic cost for health effects and all-cause mortality was calculated against a baseline concentration of fine particulate matter (10 µg/m^3). Under the BAU scenario, a province with large conventional rice area is predicted to suffer a large economic health cost. The most considerable economic health cost was assessed at approximately 12 million USD (Nakhon Ratchasima), which was ten times

[63] The all-cause mortality is a reference indicator regardless of the cause to a case-specific mortality (in this context is cardiovascular, respiratory, and lung cancer).

higher than the province with the lowest economic health cost (Nakhon Phanom). The analysis of economic cost in this study is limited, and does not cover the long term cost of chronic diseases, for example, chronic bronchitis, either in terms of medical expenses or the productivity loss. Thus, the health cost in terms of morbidity and hospital expenses is not included.

Table 4.29 Economic cost of health impact for BAU scenario in 2019 (unit: million USD)

Economic cost category by health endpoint	All-cause mortality	Cardiovascular mortality	Respiratory mortality	Lung cancer mortality
Nakhon Ratchasima	12.06	3.10	1.82	3.81
Buri Ram	5.79	1.49	0.88	1.83
Surin	4.56	1.17	0.69	1.44
Si Sa Ket	3.26	0.84	0.49	1.03
Ubon Ratchathani	3.74	0.96	0.56	1.17
Yasothon	1.26	0.32	0.19	0.40
Chaiyaphum	2.81	0.72	0.42	0.89
Amnat Charoen	1.06	0.27	0.16	0.33
Bueng Kan	1.02	0.26	0.15	0.32
Nong Bua Lam Phu	1.11	0.28	0.17	0.35
Khon Kaen	8.31	2.13	1.25	2.62
Udon Thani	1.58	0.41	0.24	0.49
Loei	2.69	0.69	0.41	0.86
Nong Khai	0.28	0.07	0.04	0.09
Maha Sarakham	2.19	0.56	0.33	0.69
Roi Et	5.07	1.30	0.77	1.62
Kalasin	2.34	0.60	0.35	0.74
Sakon Nakhon	2.75	0.71	0.42	0.87
Nakhon Phanom	0.48	0.12	0.07	0.15

Note: 1USD = 30 Baht.

As described earlier, the first scenario is business as usual (BAU), scenario 2: One Million Rai Organic Rice promotion continued, scenario 3: enhanced organic rice promotion, and Scenario 4: transformational change towards sustainability. The area of organic rice in scenario 4 is the highest followed by scenario 3, scenario 2, and BAU. The results of the scenario projections are presented in table 4.30, which represents reduction of health cost caused by PM2.5 when the organic rice area is expanded.

In addition, we also create a series of graphs for each health impact. Figures 4.50-4.54 illustrate a comparison of the economic cost of all-cause mortality across four scenarios of organic rice production. Overall, the health costs related to exposure to PM2.5 tend to decline over time, corresponding to a projected decrease in the quantity of rice residue burned. Although some areas seem to have a slight difference in health costs in the short term (2019-2025), the health costs eventually decrease in the medium term (2030-2035) (e.g., Khon Kaen). Moreover, it is evident that the health costs decline in scenarios 2-4 over time. Specifically, once the organic rice goals are reached, the residents of the provinces currently most affected by PM2.5 will benefit from this policy (e.g., Nakhon Ratchasima, Buriram, Surin, Sisa Ket, Ubon Ratchathani, and Roi Et). Comparing across scenarios with BAU, we found that the health cost decrease dramatically for the policy intervention scenario 4 compared to BAU, over 100 million USD, in year 2035.

In conclusion, this subsection aims to assess the health impact caused by rice straw burning. The human impacts analysis is applied results from GHG section with the secondary data (eg., population and GDP) to calculate health cost. The method used to assess emissions from rice burning was also used to extract a PM2.5 concentrations from rice field burning. The health impact was measured in terms of pre-mortality caused by PM2.5 based on the amended human capital model. The results show that every 10 microgram/m^3 increase in PM2.5 increases the mortality annually. The correlation between PM2.5 concentration and pre-mortality are positive and statistically significant (coefficients >0.67 at 95%). The health impact caused by PM2.5 from rice straw burning decreases over time as the organic rice area expands.

Our evidence concludes that the open rice straw burning has contributed significantly to air pollution levels and this is reflected in public health outcomes. Our findings are aligned with the public health studies in China and India (He et al., 2020; Beig et al., 2020) that the severity of health impacts is directly relevant to a level of PM2.5. Thus, the takeaway message for policy implementation can refer to the scenario, the increase in the area of organic rice conversion reduces the premature mortality in respiratory diseases.

Table 4.30 Health cost caused by PM2.5 in each scenario (Million USD)

Scenario	**2019**	**2025**	**2030**	**2035**
BAU	108.10	105.31	106.79	106.92
Scenario 2	108.10	96.74	98.10	82.50
Scenario 3	108.10	74.76	44.20	12.58
Scenario 4	108.10	72.22	0	0

Figure 4.50 Comparison of Economic cost for all-cause mortality related to PM2.5 from rice burning according to the four scenarios for years 2019, 2025, 2030, and 2035, in all provinces of NE Thailand.

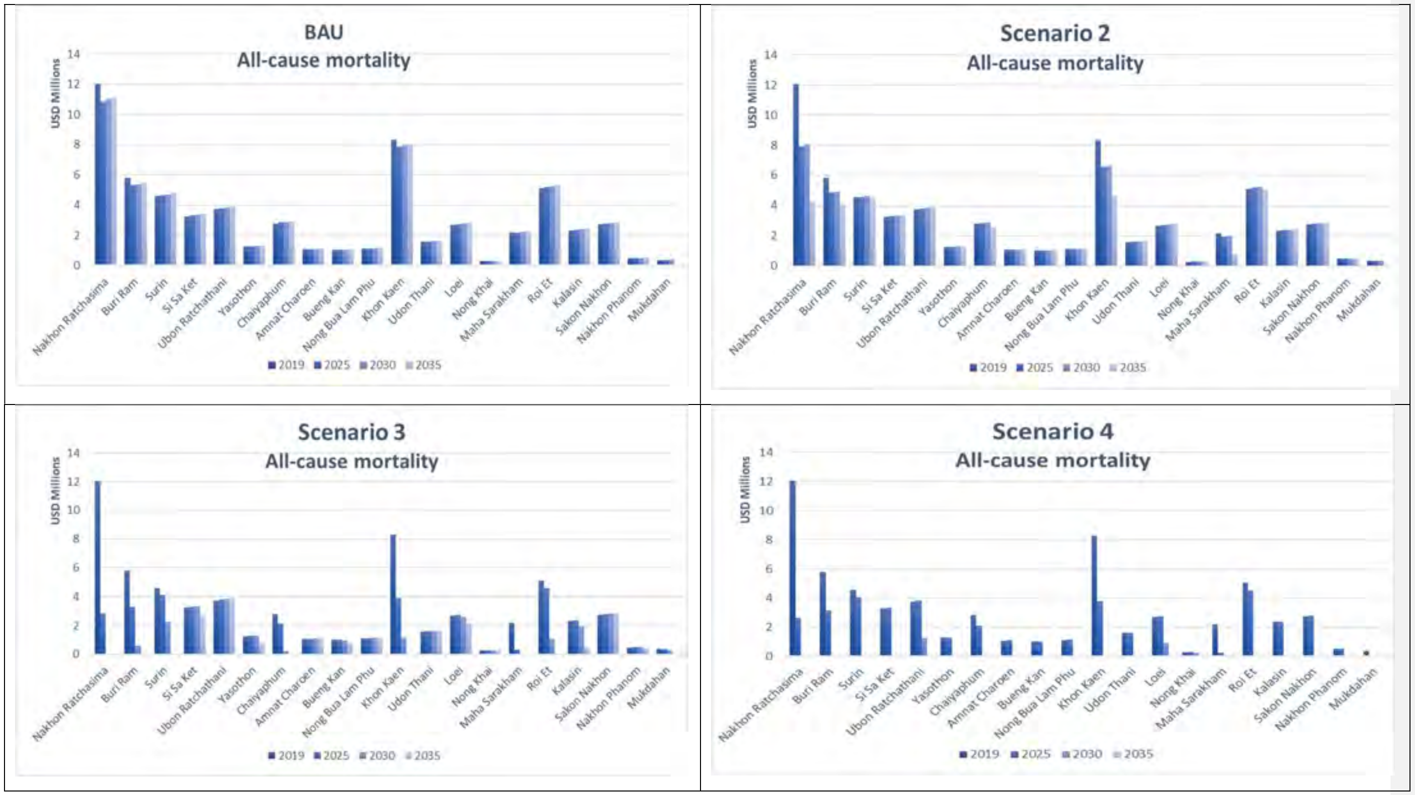


Figure 4.51. Economic cost of all-cause mortality related to PM2.5 from rice straw burning in NE Thailand provinces

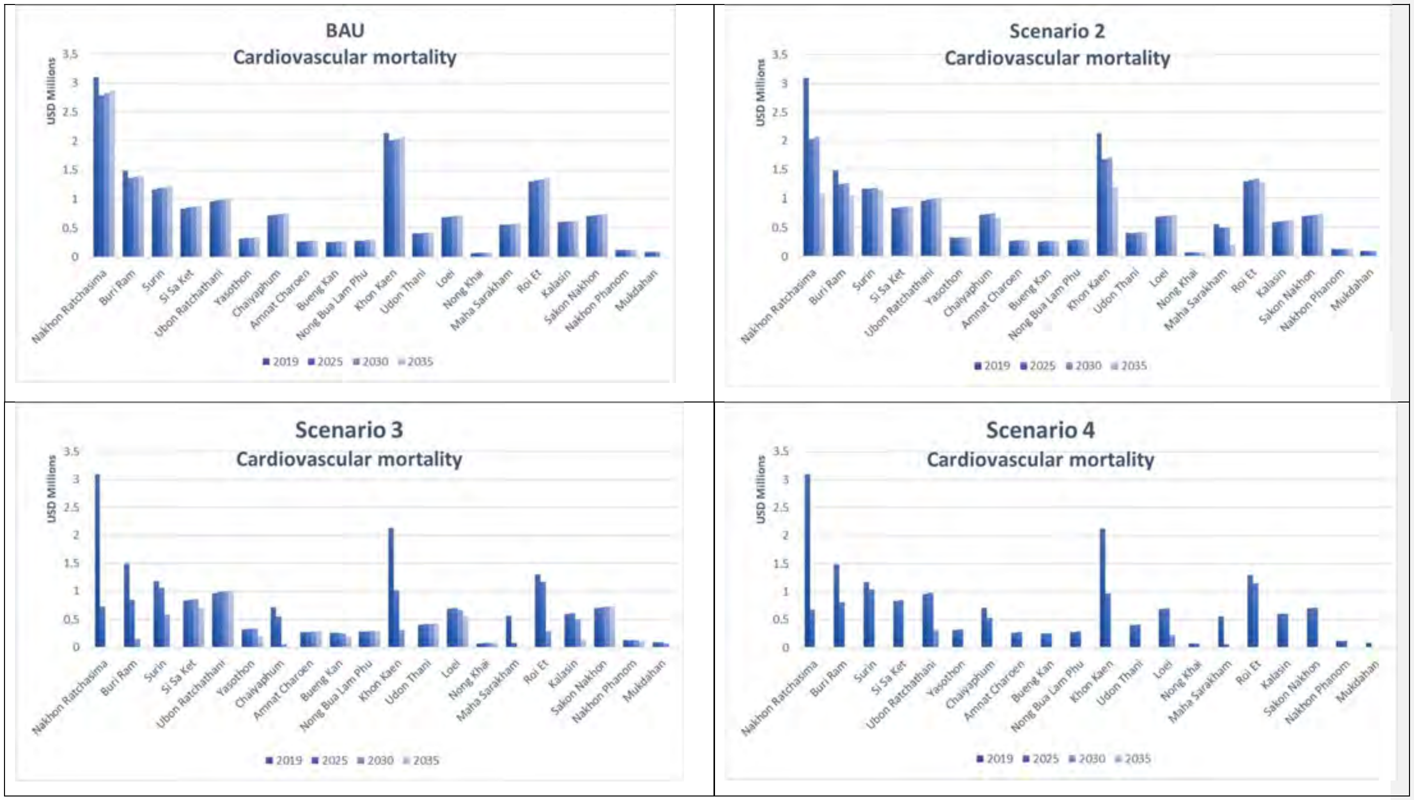


Figure 4.52 Economic cost of cardiovascular disease mortality related to PM2.5 from rice straw burning in NE Thailand provinces

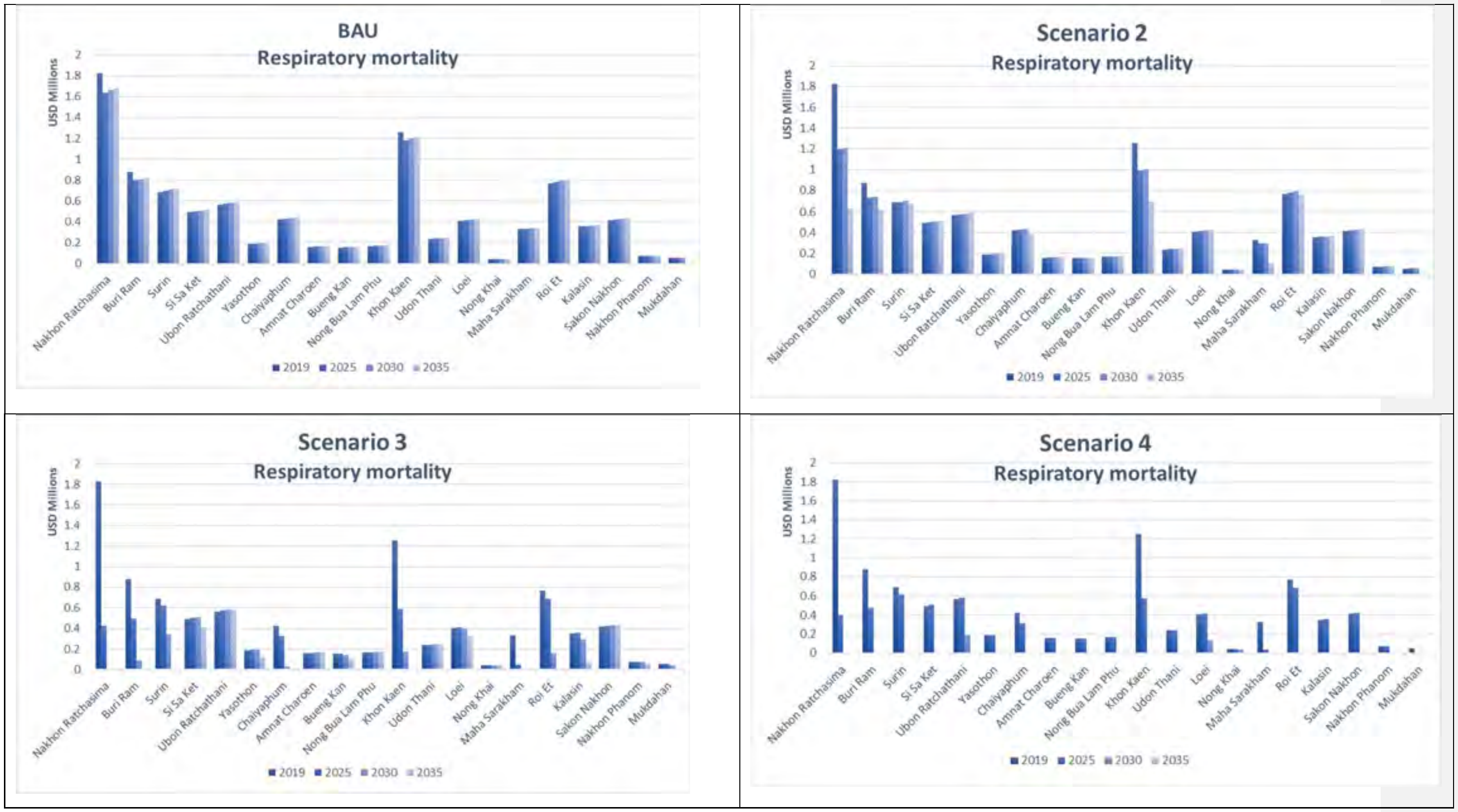


Figure 4.53 Economic cost of respiratory disease mortality related to PM2.5 from rice straw burning in NE Thailand provinces

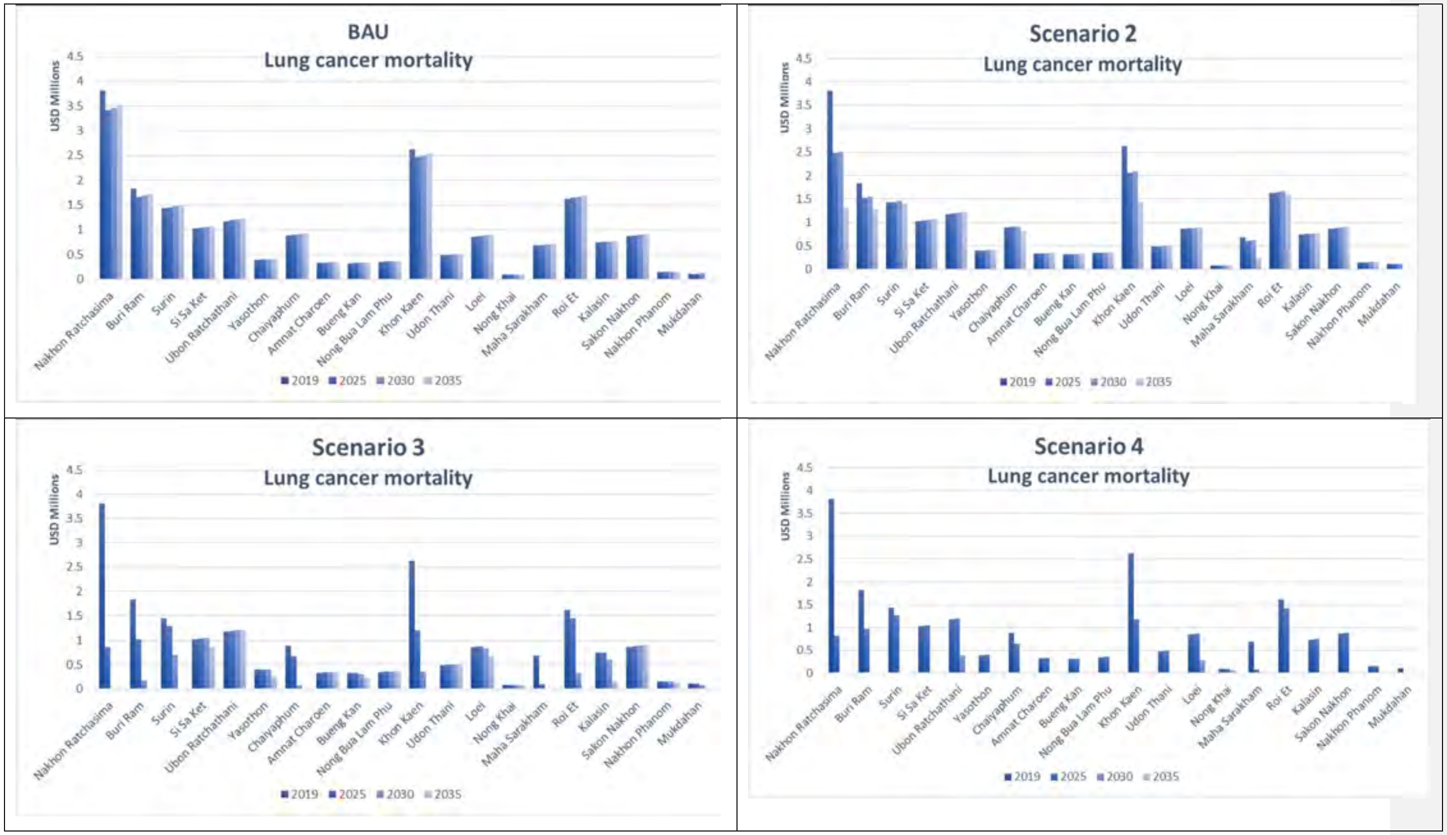


Figure 4.54. Economic cost of lung cancer mortality related to PM2.5 from rice straw burning in NE Thailand provinces

6. Socio-economic context of rice farming

One of principles of organic practice is to improve livelihoods among resource-poor small-scale farmers. Organic farming would generate additional benefit through lower of cash cost because of absence of chemical fertilizer and pesticides. Even though the labor cost may increase, farmers usually experience the net gain (profit) from premium price they receive from selling the certificated organic products (Mendoza, 2004; Bakewell et al., 2008). There are some studies conducted in Asia, Latin America, and Africa found that farmers experience an increase in their agricultural income after converting period (Bacon, 2005; Tovar et al., 2005; Bolwig et al., 2009; Valkila, 2009). The gains from adopting organic practice would also expand to food security improvement and household debt reduction (Panneerselvam et al., 2011). In addition to the economic dimension, organic practice generated additional benefits regarding social capital and community development. Qiao et al., (2016) found that even though income gain from organic certification product was still outstripped by non-farm income, market-oriented organic products created more jobs locally especially for women and was tighten social relationship.

However, there is evidence from other studies that were not favorable for organic practice in term of generating better livelihoods for small-scale farmers. Mendez et al. (2010), for example, found that even though organic and fair-trade certificated coffee farmers in Central America received premium price for their certificated coffee, they were not able to sell all of their products at the premium price resulting in an insignificant increase of their income. In addition, Blackman and Rivera (2011) reviewed 11 studies of impact of organic and fair-trade certificated products on farmers' livelihoods, and found out that there were very weak evidence that supported the hypothesis of organic certification could provide social and economic improvements at the producer level.

There have been mixed empirical evidences regarding the benefits of organic practice in terms of livelihood improvements for small-scale farmers, especially rice farmers. Further evidence is needed to demonstrate experience of organic rice farmers compared to conventional ones. Therefore, in this section, we present a socio-economic analysis relating to conventional and organic rice farmers using household survey data. Human and social outcomes of the different rice practices are described in this section. This section also provides information about what factors induce and do not induce farmers to adopt organic rice practice.

A household questionnaire was developed to collect data from conventional and organic farmers in the study areas. Table 4.31 outlines the questions asked and the issues to which they relate. The full questionnaire is available as an annex to this report. The questions elicit data that is used to identify subjective well-being/happiness concerning occupation, family life, financial status, health, and other variables, 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 organic farming practices.

Table 4.31 Household Questionnaire – Key of issues investigated.

Question	Relationship to the indicators of stocks, flows, and outcomes
Happiness (Subjective well-being)	
Questions 1-8	Subjective well-being/ happiness in social capital in general and specific time period. 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 will be asking to farmer representatives, including the medical expenses if incurred.
Agricultural land information	
Questions 9-14	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
Post harvesting information	
Questions 15-19	Practices during post-harvest to assesses outputs associated to flow of residuals and the outcomes of natural capital.
Observed biodiversity	
Question 20	The natural capital benefits such that living small animals found in the paddy field can be indicated as income and household consumption.
Choice of management system	
Questions 21-26	Whether or not organic practice is undertaken. Details of organic rice production. Driving factors that motivate farmers to uptake the organic agriculture can relate to the regression framework of adoption decision. What causes farmer to give up the practice of organic rice production?
Environmental problems	
Questions 27-28	Environmental problems in general includes pollutions and natural disaster assess the farmers' attitudes.
Income and spending	

Question	Relationship to the indicators of stocks, flows, and outcomes
Question 29	Main sources of off-farm income such as salary, wage. These off-farm income uses in part to the social capital assessment. In particular, the dividend yield of cooperative identifies the returns of investment, especially if farmer is a female shareholder, it can also reflect the gender equity.
Question 30	Monthly paid categorical items help to identify spending behavior of household.
Household debt and saving information	
Questions 31-34	Financial proxy to financial status of household
Social capital	
Question 34-37	Trust and social network capture the stock and outcomes of social capital in community.
Question 38-41	Trust and social relations
Social network	
Question 42-61	Social network regarding to agricultural activity
Behavioral bias	
Questions 62-63	Loss aversion and present bias
Rice cultivation related issues	
Question 64	Importance of different rice cultivation related issues

6.1 Sampling method

Since there are two groups of farmers in this study, organic and conventional rice farmers, the approximate sample size of the study is calculated using a stratified random sampling scheme. A total of 852 farmers were interviewed in total, 415 for conventional and 437 organic farmers, which is considered reliable for the farmer population of the Northeast at 95% confidence level with the accuracy of five percentage points. The farmer household surveys were carried out across the northern part (Khon Kaen province) and the southern part (Surin and Buriram provinces) of Northeast Thailand. The geographic stratum was used to calculate the size of the sample in each province using a proportional allocation method. A simple random sample in each stratum was drawn from the government directory of registered rice farmers (DoAE). For organic farmers, groups of organic farmers in each province were randomly selected from a list of certified organic farmer groups[64]. It is calculated as a proportioned allocation in each chosen group. Since there is no information available on the variability within the group, we assume that the variability between groups of farmers is minimal. The organic farmers from selected organic groups were asked to

[64] http://www.ricethailand.go.th/ricemarket/index.php/3-gap

participate voluntarily in the study by the head of their village. The survey was conducted from November 2020 until the first week of January 2021.

Table 4.32 presents the gender and age characteristics of our sample categorized by practices. Among 852 farmers, 415 and 437 are conventional and organic rice farmers, respectively. Five hundred and seventy-nine are female, which is around 70 percent of our sample. Seven hundred and twenty-six respondents in our sample, which covers about 85 percent of sample, were between 41-70 years old. The proportion of age between conventional and organic rice farmers are very similar for our sample. This is representative of the situation of Thailand's rice farming and indeed the agricultural sector as a whole as the average age of the head of a farming household in Thailand is about 58 years old (Attavanich et al, 2019). The younger generations of farming households tend to seek more remunerative work outside agricultural sector. More details of socio-economic information are presented in the following sub-sections.

Table 4.32. Gender and age characteristics of conventional and organic rice farmers from survey

Variables	Practices			
	Conventional (N=415)		Organic (N=437)	
	Numbers of participants	Percent (%)	Numbers of participants	Percent (%)
Gender				
Female	259	62.41	320	73.23
Male	156	37.59	117	26.77
Age				
Less 41 years	20	4.82	16	3.66
41-50 years	83	20.00	103	23.57
51-60 years	151	36.39	168	38.44
61-70 years	116	27.95	105	24.03
71-80 years	42	10.12	44	10.07
More 80 years	3	0.72	1	0.23

6.2 Household economic information

The first statistic presented in table 4.33 is the average yield per *rai* (1 *rai* is equal to 0.16 Hectare). It can be seen that the average yield of rice per *rai* from conventional and organic practices is not statistically significantly different as the p-value > 0.10. Both practices generated about 330 kilograms of rice per rai in the previous year. This represents about 2.10 tons per hectare per year, which is close to the average rice yield of the region that is about 2.18 tons per hectare per year[65]. The factors determining productivity (yield per *rai*) of these practices have been analyzed and are presented in the Rice yield production function section below.

The next statistic presented is the average cost of production per rai under both rice practices. It seems to be clear that organic rice practice has statistically significantly lower cost than conventional rice practice[66]. The costs of organic rice practice are on average lower than that of conventional practice by about 100 Baht per *rai* (about $3) or about 625 Baht per hectare (about $20.83). Chemical fertilizers and synthetic pesticides are the main factors that cause the production cost of conventional practice to be higher than that of the organic counterpart. The average income generated from 1 *rai* of organic rice is statistically significantly higher than that of conventional rice by about 800 Baht per *rai* or 5,000 Baht per hectare (about $167). This is related to the higher price of organic rice because yields of both practices are the same.

The next group of variables relate to the structure of household income. The structure of household income between conventional and organic rice farmers are somewhat different. First, income from agriculture is statistically significantly different between conventional and organic farming households. Organic rice farming households earn on average 40,000 Baht per household per year (about US$1,290) more from agriculture than what is received by conventional farming households. This difference is assessed to be caused by at least two main factors. The first factor is the fact that the price of organic rice is higher per kilogram than the price of conventional rice. Second, organic farming households in the sample had on average 6-7 *rai* (about 1 hectare) more agricultural land than their conventional counterparts.

The next item of income is non-agricultural income, which is the combination of salaries or wages earned by resident family members working outside the farm. On average, the conventional farming households received 10,000 Baht (about $333) more of non-agricultural income than organic farming households. However, the difference is not statistically significant at 90% confidence level suggesting that variance in non-agricultural income is too great to draw conclusions based on averages.

There is a statistically significant difference in the amounts of remittances sent by absent family members. Conventional farming households received a greater total sum of remittances

[65] https://www.oae.go.th/assets/portals/1/fileups/prcaidata/files/major%20rice%2062.pdf
[66] The cost of production presented here does not yet include household labor cost.

than organic farming households. This may be due to the fact that conventional farming households have more household members who migrate to work in other areas. This situation is confirmed by information from our household survey suggesting that conventional farming households on average have one more member who migrate to work in other areas when compared to organic farming households.

One possible reason could be that the conventional farming households have lower agricultural income than organic counterpart. In addition, the profit from selling conventionally grown rice is low. On average, the annual profit earned from selling conventional rice is only about 5,937 Baht (about $198) per household, while the annual profit from selling organic rice is about 28,410 Baht (about $947) per household, almost five times higher. With similar earnings from non-agricultural income and slightly higher monthly expenditure, as presented in table 4.33, conventional farming households may need to find additional sources of income to fill the need of households. Sending some of family members to work in other areas to send back remittances would be one of the answers.

From various sources of income, we can calculate average annual income of both types of farmer households. The organic rice households on average have total annual income about 135,149 Baht (or about $4,505), which comes from profit from selling organic rice, non-agricultural income, remittances, and dividends received from agriculture and non-agriculture groups (28,410 Baht + 72,291 Baht + 30,696 Baht + 3,752 Baht). For the conventional rice farmer households, the average annual income is about 131,333 Baht (or about $4,377), which also comes from profit from selling organic rice, non-agricultural income, remittances, and dividends received from agriculture and non-agriculture groups (5,937 Baht + 82,876 Baht + 40,477 Baht + 2,043 Baht). With respect to higher income of organic rice farmers, organic rice households also have more assets, which was measured by summing values of durable assets owned by households, than conventional rice households. Organic rice households on average own about 171,000 Baht (about $5,700) of assets more than conventional rice households, and this difference is statistically significant.

In respect to household economic information, the organic rice households had slightly lower monthly household expenditure than the conventional rice households. The organic rice farming households on average spend about 7,200 Baht (about $240) less on annually household expenditure than conventional farming household.

Organic rice households also had more household savings than that of conventional rice households. However, they have about 57,000 Baht (about $1,900) more household debt than the conventional rice farming households. The higher household debt of organic farmers may be due to the fact that they have more land to cultivate, which may lead them to require more funds for investing in their agricultural activities.

Table 4.33 Key statistics from household survey of conventional and organic rice farmers

Variables	Practices		*P-value*
	Conventional	Organic	
Household rice production			
Average yield of rice per rai (Kilograms)	329.747	335.254	*0.602*
	(6.559)	(8.098)	
Average cost per rai (Baht)	1,603.391	1,500.286	0.027**
	(28.942)	(35.470)	
Average income from rice (Baht per rai)	1,987.483	2,798.888	*0.000****
	(70.878)	(132.558)	
Household characteristics			
Household income			
Average agriculture income (Baht per year)	35,332.88	75,407.14	*0.000****
	(3,254.46)	(4,758.65)	
Average non-agriculture income (Baht per year)	82,876.72	72,291.83	*0.101*
	(4,517.82)	(4,578.95)	
Average remittance income (Baht per year)	40,477.71	30,696.34	*0.049***
	(3,928.73)	(3,096.93)	
Average dividends received from agriculture and non-agriculture groups (Baht per year)	2,043.17	3,752.34	*0.003****
	(355.17)	(464.80)	
Average household asset[a] (Baht)	464,849.1	635,906.6	*0.001****
	(26,459.34)	(40,114.73)	
Household economic information			
Average expenditure per month (Baht)	8,037.781	7,417.840	*0.061***
	(251.242)	(215.583)	
Average household debt (Baht)	225,842.1	282,611.7	*0.026***
	(19,004.34)	(17,127.04)	
Average agricultural land size (*Rai*)	15.459	21.869	*0.000****
	(0.578)	(0.734)	
Average household saving (Baht)	51,916.94	68,285.03	*0.087**
	(6,073.932)	(7,306.04)	
Observations	415	437	

Note: Numbers in parentheses are standard error. ***, **, and * indicate the significance level at 1%, 5%, and 10%, respectively. [a] Household asset was calculated from summing the values of durable assets own by household, but the land and housing were not counted.

6.3 Happiness and social relations information

The next information from the household survey is about happiness and social relations information of conventional and organic rice farmers. Table 4.34 first reports the findings on the levels of happiness of conventional and organic farmers households. The happiness question applied in this survey asked farmers to provide their happiness level based on evaluation of positive and negative things happening in their lives (Mahasuweerachai and Pangjai, 2019). The happiness question in this study uses 1-10 scale, in which 1 means completely unhappy and 10 means completely happy.

We then tested whether the happiness level between these two types of farmers is different using t-test. The test result suggests that even though the happiness levels between conventional and organic farmers are close, the happiness level of the organic farmers is statistically significantly higher than that of conventional farmer by almost 0.4 from 1-10 scale.

We also estimated a happiness equation to clarify whether, when controlling for other relevant variables, the happiness level of organic is still statistically significantly higher than that of conventional farmers. Our regression result confirms that the happiness level of organic farmers is statistically significantly higher than that of conventional farmers. However, we could not interpret this result as causation. Specifically, our regression result could not identify whether practising organic farming increases happiness levels or whether organic farmers are happy persons who have a positive attitude that would help them to adopt new approaches more easily than others.

In addition, we also asked both types of farmers to rank the three most important factors that alter their happiness level. The results from survey reveal that family is the most important factor to drive happiness level for both conventional and organic farmers. The second most important factor that drives happiness level differs according to types of farmers. Namely, conventional farmers identify income as the second most important factor to alter their happiness. However, health is the second most important factor that affects happiness level of organic farmers. The third factor also differs between these farmers in which health is the third most important variable to impact happiness of conventional farmers, while income is the third most important factor for organic farmers.

We also asked a set of questions that measure social relations of conventional and organic rice farmers. This set of questions consists of three questions regarding how often farmers join activities in their community, including general community activities, religious community activities, and community traditional and cultural activities. Farmers were also asked how often they engage in volunteering activities of community. Farmers were asked to provide an answer for each question based on 1-5 scale where 1 means not joining any activity at all and 5 means joining activities every time.

The answers provided by both types of farmers are tested using t-test to clarify whether levels of social ties are significantly different between these types of farmers. The results are presented in table 4.34 under the "Social relations" heading. First, conventional and organic farmers seem to have a high level of joining community activities, averaging above 4 on a 1-5 scale. However, when we compare the levels of joining community activities between conventional and organic farmers, the joining community activities levels of organic farmers are statistically higher in every type of community activity. Interestingly, when considering volunteering activities, the level of volunteering of organic farmers is not only statistically higher than that of conventional counterpart but also the size of the level is relatively large compared to community activities. Namely, the level provided by organic farmers is on average above 4 while the level of conventional farmers is on average less than 3. This means most organic farmers seem to volunteer almost every time when their community calls for volunteers to do somethings. On the other hand, on average conventional farmers responded at levels between 2 (rarely volunteer) and 3 (sometimes volunteer).

The results of social relation suggest that organic farmers have more social relation than conventional rice farmers especially in the volunteering dimension. This would be the part of social capital that organic farmers may have more prosocial behavior toward others in their community than conventional rice farmers. This behavior may be developed through group cooperation because organic rice farmers participate in group activities more than convention farmers for both male and female farmers as presented in table 4.32 under "Number of groups joined by farmers". On average, organic farmers, both male and female, join one more group than conventional farmers, and this difference is statistically significant. Chandoevwit and Thampanishvong (2016) report volunteering value of Thai population using happiness equation. This study found that people who usually volunteer are happier than those who have not volunteered, and through monetary valuation approaches found that increasing in happiness regarding to volunteering provides value between $52-$152 per household.

Table 4.34 Happiness and social relations information of rice farmers

Variables	Practices		*P-value*
	Conventional	Organic	
Happiness information			
Average assessed happiness level	8.098 (0.081)	8.384 (0.076)	*0.010***
Factors influencing happiness (Percentage)			
Family	40.39	41.32	-
Income	24.09	20.78	-
Health	21.41	21.69	-
Others	14.12	16.21	-
Social relations			
Joining general community activities	4.328 (0.052)	4.462 (0.043)	*0.045***
Joining community religion activities	4.130 (0.064)	4.485 (0.034)	*0.000****
Joining community traditional and cultural activities	4.335 (0.047)	4.524 (0.031)	*0.000****
Community volunteering activities	2.952 (0.077)	4.183 (0.045)	*0.000****
Number of groups joint by farmers			
Female farmer	1.703 (0.057)	2.209 (0.029)	*0.000****
Male farmer	1.628 (0.076)	2.256 (0.050)	*0.000****
Observations	415	437	

Note: Numbers in parentheses are standard error. ***, **, and * indicate the significance level at 1%, 5%, and 10%, respectively.

6.4 Comparative analysis of socio-cultural and economic interests of conventional and organic rice farmers

We next analyzed the importance famers gave to different rice cultivation related issues, which included economy, environment, health, and social and culture issues. Namely, we asked how important these issues were for the success of rice cultivation. Farmers' responses were measured using a 1-5 scale, where 1 means not important and 5 means very important. Table 4.35 presents the results distinguished between conventional and organic rice practices.

The first set of issues addressed were economic issues, concerning the importance farmers gave to profit from selling rice, yield, and labor productivity. On average, all economic related issues were scored highly, at a level of more than 4 out of 5, suggesting on average that all these factors are important for both types of rice farmers. When considering between organic and conventional rice farmers, organic rice farmers gave more statistically significant attention to rice sales profit, and labor productivity than conventional rice farmers. However, yield of rice receives the same degree of attention from both types of farmers. In addition, among the surveyed farmers, rice yield was the most important variable amongst the economic variables, receiving the highest score in relation to importance when compared to profit from selling rice and labor productivity. This indicates that rice yield was the main economic indicator to measure the success of rice cultivation in the eyes of both types of farmers.

The next set of issues relate to the environment, which includes water quality, air quality, and landscape amenity. It is clear that organic farmers provide statistically significant higher importance scores for water quality and air quality on rice cultivation than conventional farmers. This information suggests that organic farmers think better water quality and air quality are more important for rice cultivation than conventional farmers. However, note that even though conventional farmers give lower importance scores on these issues than organic farmers, these importance scores provided by conventional farmers are still high, at a level of 4.3-4.4 out of 5 suggesting that water quality and air quality are also important for them. For the landscape amenity, the importance scores from both types of farmers are not statistically significantly different suggesting that both types of farmers give the same importance score for landscape amenity.

Next, farmers were asked about health factors, including issues of food safety and health risks from agriculture. Both conventional and organic farmers see these issues as the most important issues for the success of rice cultivation. They were rated the highest among other issues including economic, environment, and social issues. The importance scores for these issues were the highest among all the issues asked, ranging from 4.6-4.8 out of 5 suggesting health issue is the most important for rice cultivation placed by both conventional and organic rice farmers. When comparing between organic and conventional farmers, the organic farmers give higher importance to factors related to food safety and minimizing health risks from agriculture, with a statistically significant difference in scores compared with those of conventional farmers. Note that minimizing health risks from agriculture was given the highest importance scores of all the issues listed from both types of farmers. This result is consistent with the results we have from choice experiment where the fatality risk from pesticide poisoning is given the highest value or in another word highest concern from both types of farmers.

The final set of issues assessed were the social and cultural factors that rice farmers gave attention to in rice cultivation. This set contained two related topics. The first one was whether it is important to them that their children participate and continue in rice cultivation. Organic farmers provided statistically significant higher importance scores on this issue than their conventional counterparts. This may be due to the fact that organic farming could provide their children not only food security but also profit. Even though the importance scores for this issue among conventional farmers are lower than organic farmers, with a statistically significant difference, we could not interpret this result as an indication that conventional farmers do not want their children to participate and continue rice cultivation. This is because the score for this topic from conventional farmers is also high, at a level of 4.2 out of 5.

The second issue in this set related to the roles of women in rice cultivation. Both types of farmers see this issue as important because the importance scores provided by them are relatively high, ranging between 4.4-4.6 out of 5. Amongst the farmers surveyed, organic farmers see the role of women being relatively more important than conventional farmers. Our data would not be able to clarify causation, however we could speculate that this pattern may be associated with the facts that organic farmers usually create, and operate as, an agricultural group, and women tend to have some significant roles to manage and participate in such groups.

Table 4.35 Scores given by rice farmers to the importance of different issues for the success of their rice cultivation (on a scale of 1 to 5).

Variables	Practices		P-value
	Conventional	Organic	
Economic issues			
Profit from selling rice	4.247	4.464	0.002***
	(0.055)	(0.043)	
Rice yield	4.621	4.636	0.912
	(0.137)	(0.032)	
Labor productivity	4.192	4.383	0.004***
	(0.050)	(0.043)	
Environmental issues			
Water quality	4.319	4.482	0.008***

Variables	Practices		P-value
	Conventional	Organic	
	(0.046)	(0.041)	
Air quality	4.429 (0.038)	4.521 (0.035)	0.073*
Landscape amenities	4.494 (0.036)	4.492 (0.036)	0.980
Health issues			
Food safety	4.618 (0.033)	4.751 (0.025)	0.001***
Minimising health risks from agriculture	4.712 (0.028)	4.824 (0.023)	0.002***
Social and Cultural issues			
Youth participation in rice cultivation	4.270 (0.048)	4.446 (0.042)	0.006***
Women's empowerment	4.465 (0.041)	4.585 (0.034)	0.022**
No of Observations	385	386	

Note: Numbers in parentheses are standard error. ***, **, and * indicate the significance level at 1%, 5%, and 10%, respectively.

6.5 Factors that influence decision to adopt/ not adopt organic rice farming

Our household economic survey also elicited information related to perceptions on organic rice farming. In this set of questions, both types of farmers were asked to rank the three most important factors that influenced their decision to adopt organic rice practice.

We start with the perception of farmers who are growing organic rice. Table 4.36 presents the survey results from the 437 organic farmers relating to the reasons why they switched from conventional rice practice to organic rice practice. Organic rice farmers were asked to identify three main reasons for switching from conventional to organic rice practices. Note that results presented by table 4.36 were calculated from the top ranked responses by farmers. More than 85 percent of current organic farmers ranked good health as the number one factor that persuaded them to switch from conventional practice to organic practice. The higher price of organic rice is ranked as the second most important factor followed by the lower cost of organic rice. Note that the high demand and relationship in community share similar proportion as the lower cost of organic and high demand of organic rice. From these results, good health is clearly the main driver for current organic farmers to switch from conventional practice to organic practice.

Table 4.36 Survey responses to what do organic rice farmers switch from conventional to organic?

Variables	Percent
For good health	85.29
For higher price of organic rice	4.09
For lower cost of organic rice practice	3.81
Because of high demand	3.54
To create relationship in community	3.27
Total	100

A second set of questions was asked to the 415 conventional farmers for their perception on organic rice practice, and the results are shown in table 4.37. The first question asked what are the three most important factors that prevent conventional farmers from switching to organic farming. We used information provided by farmer to calculate the proportion of how much each reason was chosen as number one reason. The number one barrier preventing conventional farmers to adopt organic practice was lack of knowledge of organic practice. About 41 percent of conventional rice farmers gave this reason as the number one factor that prevents them to change to organic practice, suggesting that they do not know how to start to cultivate organic rice as no-one had provided them with information on the processes of starting organic rice practice.

The second most important factor that was reported as a barrier to adopting organic practice was that it was considered too difficult to obtain an organic certificate, which takes a significant amount of time, labor, and money. The third most important barrier reported by conventional farmers was that it would be impossible for them to stop using chemical fertilizers and pesticides because if they stop using them it would be difficult to prevent damage from pests and lowering yield due to lack of fertilizer. The fourth barrier to prevent a change to organic rice practice is conventional farmers have the perception that organic rice provides less profit than conventional rice, mainly because of the perception that yields from organic practice is significantly lower than conventional rice.

Table 4.37 Survey responses to what is the main factor preventing conventional rice farmers from switching to organic rice practice?

Variables	Percent
Lack of knowledge of organic rice practice	41.20

Variables	Percent
Getting organic certification is too complicated	24.40
Difficult to manage rice field without chemical fertilizer and pesticide	15.20
Less profit	12.40
Cost of organic certification is too high	2.80
Others	4.00
Total	100

A second question put to conventional farmers was to ask them to identify what factors would incentivize them to adopt organic rice practice. Responses to this question are presented in table 4.38. The incentive considered most important by conventional farmers to drive them to adopt organic farming is a subsidy from the government. This information may reveal the concern of conventional farmers for income uncertainty when switching from conventional rice practice to organic rice practice (Benyishay and Mobarak, 2019; Amber et al., 2020). Many conventional rice farmers do not know how to cultivate organic rice and have no experience growing it, which means during the earlier stages of transition farmers may not get high yields of rice (Mahasuweerachai, 2021). From this circumstance, getting subsidy especially during the early stages of adoption may reduce income uncertainty and respond to the concerns of the farmers. Note that subsidy especially during the transition from conventional to organic rice would be able to incentivize farmers to switch when compared to no subsidy available especially if subsidy is enough to cover the risk during transition period. This evidence could be seen from an increase in organic rice area during the implementation of one million rai program between 2017-2020. The area of organic rice was on average increased by about 112,700 rai (18,041 hectare) per year, which was almost 10 times higher than that before the program started[67]. However, please keep in mind that subsidy alone may not be enough to significantly increase rate of organic adoption as other factors would also involve farmers' decision on adoption.

The next factor considered most important by conventional farmers that would persuade them to adopt organic rice practice is health benefits. If there is clear information that organic practice would benefit health of farmers when compared to conventional practice, conventional farmers would see this benefit and switch from conventional to organic practices. The third incentive that conventional farmers consider to be most important to incentivize them to adopt

[67] The average increase of organic rice area before one million rai program is about 12,721 rai (2,035 hectare) per year.

organic rice is being offered a higher price for organic rice. If they can sell organic rice at significantly higher price than conventional rice they would likely to switch to organic practice. This finding suggests that farmers expect to get premium price for organic rice. Therefore, if they can surely sell their organic rice with premium price, it would be likely to increase adoption of organic practice. These three factors alone cover over 70 percent of responses from conventional farmers to this question suggesting that these three incentives would be important drivers that could be focused when designing interventions to increase rate of organic rice farming adoption.

From these three main factors that would lead farmers to adopt organic rice practice, subsidy especially during the transition period would be the salient factor that would help farmers to decide whether they should adopt organic practice as the benefit of increasing income from premium price of organic rice and health benefit will take longer time for farmers to experience and realize such improvements. However, it does mean that premium price and health benefit do not take any intension from farmers when they decide whether to adopt organic practice. If temporary subsidy, for example, is available with secure market that could ensure premium price for farmers, it would significantly increase chance for farmers to adopt organic rice practice.

Table 4.38 Survey responses on the key incentives to encourage conventional rice farmers to switch to organic rice practice

Variables	Percent
Subsidy from the government	33.87
Health benefits	21.77
Higher price of organic rice	17.74
Following village leaders	8.47
Availability of market	7.26
Following neighbors	4.44
Following government suggestion	2.82
Following relatives	2.42
Others	1.21
Total	100

Note: The preset variables were developed from the information provided by our focus groups. However, we also allowed farmers to suggest other incentives not listed in the questionnaire.

The third question in this set was posed to conventional farmers who used to grow organic rice but who have since switched back to conventional rice practice. They were asked to identify the variables that disincentivized farmers from continuing with organic farming. A total of 44 farmers (10.60 percent of conventional farmer samples) responded to this question and their responses are summarized in table 4.39. The most important factor reported by this group of farmers, 36.59 percent, was that the yield of organic rice was too low when compared to conventional rice practice. Note that this variable referred to low yields from organic rice farming after the three-year transition period. This group of farmers reported to us that they experienced lower yields of organic rice than conventional rice when already performing organic practice for some period of time. Follow up questions revealed that these farmers experienced that organic rice practice could not provide them as much income as conventional rice. Another 24.39 percent of these farmers gave their reason for switching back to conventional practice as the process of getting organic certification was too complicated. For 19.51 percent of these farmers, the most important factor was that they could not absorb yield losses during the first three years of switching to organic rice practice. Note that the most likely time that this group of farmers would have tried to switch to organic practice would have been before the One Million Rai program had started. This programme provides three years of subsidy for farmers who adopt organic rice practices. It began to be implemented in 2017, so most farmers in this programme had not yet passed the transition stage when our survey was conducted. The fourth most common reason that disincentivized 17.07 percent of these farmers to not continue organic rice practice was uncertainty of the organic rice market. Farmers citing this reason said that it was difficult for them to find the market to sell organic rice. Follow up questions revealed that these farmers usually ended up selling their rice at general market and received no premium price as expected.

Table 4.39 Factors disincentivized organic rice farmers to continue organic rice practice

Variables	Percent
Yield of organic rice is too low even after transition period	36.59
Getting organic certification is too complicate	24.39
Yields of organic rice dramatically decreased during the transition	19.51
Uncertainty of organic rice market	17.07
Cost of organic certification is too high	2.44
Total	100

Part 5: Summary of Measures and Scenarios Evaluation

1. Introduction

The rice sector plays an important role in the social, economic, and environmental development of Thailand. The main purpose of this study is to assess the responses of various variables in rice system based on different scenarios, which focus on different degree of landscape changes between conventional and organic rice areas in the northeast region of Thailand from 2020-2035.

The development of the scenarios is presented in Part 3. In summary, these are based on plans, and policies including the One Million Rai Organic Rice Farming pilot project and Thailand's 20-year strategic plan (2017-2036), which includes a plan for developing Thailand's organic products. The scenario analysis is based on 16 year timeframe, starting in 2019 and ending in 2035. Based on the key instrument and policy, there are four scenarios differed by the proportion of conventional and organic rice areas.

The business as usual (BAU) scenario defines the government's One Million Rai Organic rice program is implemented according to published targets. Participants targeted were farmers who continue to practice organic rice farming in subsequent seasons. In this scenario, no new policy initiatives are implemented for further promotion of the organic sector after initial targets are met. BAU scenario assumes that the expansion of the One million rai Organic Rice promotion program is currently taking place through the end of 2021. The participating farmers successfully adopted the organic practice on their lands and were certified as "Organic Thailand". On this basis, it is assumed that the areas producing certified organic rice will reach just over one million rai (173,027 hectares) in 2025. The BAU scenario assumes that the targets are met by 2025. And that the organic rice area is maintained until at least the year 2035.

For scenario 2, One Million Rai Organic rice program is continuously implemented after 2020 to increase the adoption of organic agriculture by Thai rice farmers, expanding the area under organic production by a million rai every five years. There are other areas currently undergoing a transition to organic. It takes at least three years for a farmer practicing organic farming to qualify for certification, so the rate of increase of area under organic rice production generated through this program will be realized after 2021. In addition, this scenario assumes that policy initiatives to support the adoption of organic farming continue to be developed between 2020 and 2035 to continue to expand the adoption of organic agriculture by Thai rice farmers at around one million rai every five years. As a result, the area for organic rice production would increase gradually. This scenario expects that the organic rice area in the northeast will expand to 640,000 hectares in 2035 or 11.93 percent of total rice area.

For scenario 3, this scenario assumes that the One Million Rai Organic rice and other intervention programs are continuously implemented after 2020 to increase the adoption of organic agriculture by Thai rice farmers. According to the MoAC, the promotion of organic rice cultivation aims mainly in the Northeastern region. The policy initiatives collaborate with other ministries, including the Ministry of Natural Resources and Environment, the Ministry of Public Health, the Ministry of Commerce between 2020 and 2035. Thus, the organic rice expansion in this scenario is proactive. This scenario expects that the organic rice area in the northeast will expand to about 2,400,000 hectares or 41 percent of total rice area by 2035.

For scenario 4, it is assumed that demand for organic rice production has dramatically increased and that powerfully stimulates to reach the government target, organic and sustainable agriculture by 2030. It means that 100 percent of agricultural land in the northeast area (149 million rai or 23 million hectares) to be cultivated organic or sustainable practices. According to the government target, organic farming practices should be applied nationwide in 40 million rai by 2030, and 80 percent of that area would produce organic rice. Thus, this ultimate scenario expects that the organic rice area in the northeast will increase to 5,120,000 hectares or 87.46 percent of total rice area.

In Part 4 we have presented an analysis of variables that respond to the land use changes under different proportion of organic and conventional rice areas from these scenarios. The variables affected by different rice practices focus in this study relate to natural capital, human capital, produced capital and social capital. For natural capital, this study focuses on greenhouse gases emissions and changes in biodiversity from conventional and organic rice practices. Impacts on human health from pesticide poisoning and air pollution from different rice cultivation practices are explored for measuring change in human capital. Rice yield and cost of cultivation, which represent profit gained by farmers, between conventional and organic rice practices are also estimated. These changes are modelled based on projected land use changes under each scenario, and quantified. For social capital, it is not quantified, however a qualitative analysis revealed the effects of different rice practices on cooperation and social relationship among farmers. .

In addition, the analyses of variables responded to land use changes under different scenarios are gathered to perform benefit-cost analysis. The results from benefit-cost analysis will shed light on what scenario would provide the highest net benefit when the full value of environmental, social, and human dimensions of rice food systems are considered to inform decisions in addition to regular economic considerations. Furthermore, the results from benefit-cost analysis can demonstrate the trade-offs that policy makers could use to quantitatively identify the best scenario compared to BAU

2. Greenhouse gas emissions

For GHG emissions, this study covers three main sources of GHG emissions from the rice fields. The first one is GHG emissions that are generated directly from the cultivation process. The second source of GHG emissions in rice field is from the soil, which is related to soil carbon stock. The third source of GHG emissions in rice field focused in this study is the emission from rice straw burning after harvesting rice.

Agriculture is the main source of methane (CH_4) and nitrous oxide (N_2O) emissions. Flooded rice represents a major source of atmospheric CH_4, while the use of synthetic fertilizer for increasing crop production causes N_2O emission. However, the actual amount of N_2O emission varies depending on fertilization intensity, fertilization type and other factors. Therefore, CH_4 and N_2O were considered in the GHG emission from the rice fields with different fertilizer management.

Long-term GHG emission estimations over 2019-2035 under different rain-fed rice field management practices including conventional and organic practices were predicted using the DNDC model, described in Part 4. This model includes input data including data of climate, soil textures and properties, crop, land and water management. These data were input in the DNDC model to predict carbon and nitrogen cycling in agroecosystems.

The projected annual GHG emissions from conventional and organic rice field management practices over 2019- 2035 took into consideration variables of field managements (organic and conventional managements). Under both field management practices, the organic rice fields tend to generate higher CH_4 emissions than conventional rice field management practice (16.05 and 14.95 tons CO_2 equivalent per ha per year, respectively) approximately 7 percent. However, N_2O emission from the organic rice field is lower than conventional rice field (0.40 and 0.76 tons CO_2 equivalent per ha per year, respectively) about 48.6 percent because the manure in the organic rice field provides lower available N such as nitrate, which is the substrate of N_2O production than the chemical fertilizer in conventional systems.

The total GHG emissions combine the projected emissions of CH_4, and N_2O. CH_4 emission is the dominant GHG emission in this study. The estimated total GHG emission from the organic rice fields ranged from 15.28 to 18.39 tons CO_2 equivalent per ha per year while the conventional rice field ranged from 14.57 to 17.64 tons CO_2 equivalent per ha per year. The estimated total GHG emission in organic rice fields is slightly higher than in conventional rice fields by approximately 5 percent.

Long-term soil organic carbon (SOC) stocks estimations over 2019-2035 in all practices are expected to increase over the years. The SOC stocks in organic rice fields tend to be higher than in conventional rice fields approximately 11.3 percent because more organic matter such as manure is added into the organic rice fields than into the conventional rice fields. Although CH_4 emission and total GHG emissions increase from Scenario 2, 3, and 4, these scenarios promote SOC which is important for CO_2 mitigation because C, a source of CO_2 production, can be stored in soil as SOC.

The next source of GHG emission is from rice straw and stubble burning. Rice straw and stubble burning are another main concern in paddy rice production, as this generates not only GHG emissions, but also other pollutants in the form of fine particulate matter (PM 2.5). Rice residue burning is prohibited in the organic rice practice. However, residue burning is not uncommon in conventional rice cultivation. Values from Junpen et al (2018) were used to project air pollution from rice residue burning according to the diminishing area of conventional rice according to the four scenarios from 2020 to 2035.

With respect to greenhouse gases, there would be a substantial reduction in the emission of GHG from rice residue burning as the organic area expands to 2035 from

1.2 million tons of CO2 equivalent emitted in BAU to 1.09, 0.72, and 0.15 million tons of CO2 equivalent emitted in Scenarios 2, 3 and 4 respectively.

Taking together the total GHG emission from rice practices generated by cultivation practices and rice straw burning outlined in Part 4 and summarized above, the total emissions from rice fields under organic practices were assessed to be slightly higher than that from conventional practices. Table 5.1 summarizes the total GHG emissions from rice fields in the Northeast of Thailand projected for each scenario. For the cumulative GHG emission from 2019 to 2035, the BAU will be producing 108.54 million tons of CO2 equivalent, while more intensive organic rice scenarios will be releasing 108.90, 110.26, and 112.25 million tons of CO2 equivalent respectively. Note that when carbon sequestration capacity in the rice fields is included to overall GHG emission, the overall GHG emission from organic practice will be lower than that of conventional practice. This calculation will be shown when the amounts of GHG from cultivation, rice straw burning, and soil organic carbon are converted to monetary values.

Table 5.1 Total accumulated GHG emission from the conventional and organic rice based on each scenario in the Northeast of Thailand (Million tons of CO2 equivalents)

Scenario	Year			
	2019	2025	2030	2035
BAU	97.36	93.9	95.34	108.54
Scenario 2	97.36	93.99	95.50	108.90
Scenario 3	97.36	94.29	96.11	110.26
Scenario 4	97.36	94.31	97.82	112.25

3. Biodiversity and ecosystem services

Biophysical modeling to identify variability of insects was implemented to assess the responses of biodiversity in rice field based on landscape change in rice farming practices, conventional practice versus organic practices, of 4 scenarios. The study follows the framework shown with the field data collected at the 24 designated plots using trapping methods. The random forest model was applied to quantify the correlation between biodiversity and site-specific covariates composed of climate and land use to predict changes in biodiversity at the regional level. For the impact of biodiversity on ecosystem services, the Bayesian framework was then used to quantify the relationship.

The study results suggest that the two rice farming practices provided slightly different habitat quality with predatory insect found in the organic rice farming system. This difference consisted in the diversity of the sets of families. For aerial insects, both systems have similar diversity of insect. In the analysis of feeding guilds, we found that the average abundance of both plant feeding and predatory insects was greater in conventional farming sites than in organic farming sites while the overall diversity of insect families is higher in organic rice farm fields but not significant at both species-level and class-level since most of the species were spatially clumped and were absent from many sample plots.

From the regional prediction of normalized biodiversity based on organic rice farming conversion scenarios, the secondary data from other studies, which increase observations from another five provinces of the Northeast region, was integrated to our field analysis. The Random Forest model was used to predict the normalized diversity index of insects at the landscape level using the landscape covariates and current land use data. Based on the prediction, most of the organic farming practice sites had higher diversity indices than the predicted sites with conventional method. The prediction of the future scenarios at year 2020, 2025, 2030, and 2035 was done to see the change and compare biodiversity index across conversion scenarios. From the results of this prediction, the biodiversity increased as the percentage of land practiced in organic rice farming increase from 2020 to 2035. Scenarios 3 and 4 projected the highest rates of increase of normalized biodiversity index as compared with BAU and Scenario 2 throughout the time based on the higher incremental rate of conversion to organic rice farming.

The relationship in different farming practices, the latent variables of biodiversity and yield/cost of rice farming were identified and modeled using Bayesian framework. The results showed that while the different practices have a significantly influence on biodiversity, the effect of latent biodiversity on the yield/cost ratio was not significant. However, the insignificant different effect of yield/cost ratio between these two practices would not be interpreted as abundance of biodiversity. The variability of insects had no effect on yield and cost of rice production. The use of biodiversity to determine the expected difference of profit and cost between organic and conventional practices here is limited, due to mismatching between in most of the household and field sampling dataset. In addition, data from the farmer household survey and choice experiment method, reveal the importance of insect diversity on rice cultivation cost. Namely, from the household survey, given the cultivation cost of organic practice is lower than conventional practice by about $19 per hectare. About 80 percent or $15.20 per hectare of this saving cost is generated from avoiding pesticide use in the organic rice fields. Note that the value of insect diversity from household survey would be treated as the very low-end estimation of insect diversity because other functions such as better natural food chain due to insect diversity, which induce more ecosystem services, are not taken into account. The value of availability of beneficial insects in rice fields elicited by choice experiment method also suggests the similar pattern as the household survey. The availability of beneficial insects in rice fields receive significant attention from farmers. This attention can be converted to the value of availability of beneficial insects placed by farmers, which is about $154.67 per hectare. Since organic rice practice generates significantly more abundance of insects than conventional practice and the function of this biodiversity abundance would benefit rice cultivation through at least cost saving, we can calculate changes of this value based on each scenario where organic rice practice area is varied as presented. Table 5.2 uses value from household survey to estimate the benefit gain from biodiversity abundance for each scenario.

Table 5.2 Benefit from availability of beneficial insects for each scenario (unit: USD)

Scenario	2019	2025	2030	2035
BAU	1,556,138	2,883,786	2,883,786	2,883,786
S2	1,556,138	5,333,333	8,000,000	10,666,667
S3	1,556,138	13,333,333	26,666,667	40,000,000
S4	1,556,138	13,824,171	85,335,882	85,335,882

4. Health impacts

This section describes the benefit and cost analysis assessing the impact of rice production on human wellbeing. Rice production based on the conventional practice indicate the negative health externalities from two sources, namely chemical pesticide use and air pollution. In this study, we assess the health effects of the use of pesticide in rice production, based on information from farmers from the household survey data and choice experiment data. We also assess the effect on human health in rice production relates to air pollution from rice straw and waste residue burning.

Starting with the effect of pesticides on farmers' health, data from our survey shows that 2.17% of conventional farmers reported symptoms of pesticide poisoning while a total of zero organic rice farmers reported such symptoms. From our survey, most conventional farmers affected by pesticides reported minor symptoms, i.e. skin irritation, nausea, and headache, and the average medical treatment cost was reported to be about $13 per individual. When extrapolated to the entire rice farmer population, the total annual cost of minor illnesses from pesticides would be about 1.17 million USD.

The health cost calculated from survey data is considered the minimum health cost that could reliably be calculated based on visible cost of treatment. However, this data cannot capture the long run effects of pesticides that may cause chronic diseases affecting internal organs such as liver and neurological system, which result in serious illnesses or death. To cover the invisible and long run effects of pesticides, we employed choice experiment method to elicit value of reducing the fatality risk caused by pesticide poisoning directly from farmers' preferences. The result from choice experiment methods reveals that on average both organic and conventional rice households place the value of fatality risk reduction caused by pesticide poisoning about $472 per household per year. This value can be converted to per hectare of rice cultivation area, which is about $251.67 per hectare. Table 5.3 presents the related benefit of health cost reduction from conversion to organic cultivation of rice in each scenario.

Table 5.3 Benefit from reduction of fatality risk from pesticide poisoning (unit: USD)

Scenario	2019	2025	2030	2035
BAU	23,217,685	41,952,873	44,679,342	48,403,476
S2	23,217,685	77,668,895	124,333,467	180,966,444
S3	23,217,685	198,216,160	426,560,092	681,602,817
S4	23,217,685	205,716,147	1,203,705,802	1,288,589,487

The next part of health evaluation is health cost caused by the emission of fine particulate matter (PM2.5) generated in the process of rice straw and stubble burning. Agricultural residue burning, including the burning of rice residues, contributes approximately 30 percent of the fine particulate matter (PM2.5). We present a brief summary of health cost assessment and then present the benefit of PM2.5 reduction of organic rice conversion in this section.

The assessment of health costs starts by evaluating the health impacts of exposure to PM2.5, above a concentration of 10 μg/m^3 measured in premature mortality caused by cardiovascular disease, respiratory disease, lung cancer, and all-cause mortality. Since certified organic rice production does not allow open field burning after harvest, it is assumed that there is no emission of PM2.5 from these areas. Emission sources of PM2.5 are assumed to be from other agricultural fires, including from conventional rice fields. To segregate the emissions from conventional rice fields from other sources of agricultural waste burning, we applied PM2.5 concentration data recorded during November-February, the season of rice residue burning. The amended human capital model (AHC) was used to assess the economic cost of health impacts in the subsequent step. The results from the AHC model are considered to be a lower bound of health cost estimates from rice production.

These health costs were linked to the benefit of PM2.5 reduction based on the scenarios of rice cultivation area. These are summarized in Table 5.4. The BAU Scenario is used as a baseline to compare with future increases in the organic rice area along three alternative scenarios, the continuation of the One million rai organic rice promotion programme (Scenario2), Enhanced organic rice promotion (Scenario3), and a Transformational change towards sustainability (Scenario4) in the years 2025, 2030, and 2035, respectively. Essentially, the rate of organic rice expansion intensively increases from scenario 2 to scenario4. We assume that with the decrease in conventional rice areas, and the corresponding decrease in potential emission sources of PM2.5, the health cost associated with PM 2.5 declines. Under this consideration, the health cost per hectare is expected to reduce over time as the conventional rice area decreases.

Table 5.4 Health cost of exposure to over 10 μg/m^3 of PM2.5 in each scenario assessed by AHC model (unit: Million USD)

Scenario	**2019**	**2025**	**2030**	**2035**
BAU	108.10	105.31	106.79	106.92
Scenario 2	108.10	96.74	98.10	82.50
Scenario 3	108.10	74.76	44.20	12.58
Scenario 4	108.10	72.22	0	0

5. Rice production

This section analyzes the production costs and returns of cultivating rice using conventional and organic rice practices. The results of yield prediction and cost prediction of both types of practices are combined with land use changes to estimate the impacts of yield and cost differences between these practices based on each scenario.

Starting with cultivation cost, the difference of cultivation cost, mainly from pesticide and chemical fertilizer cost, between organic and conventional rice practices were observed through household survey data from both types of farmers. The data reveals that the cost structure of both practices is similar. However, conventional rice practice shows higher cost than organic counterpart by about $20.83 per hectare. There are two main costs that contribute to the higher overall cost of conventional practice in comparison with organic practice. The first one is pesticide costs, which alone covers about 80 percent of additional cost (about $16.67 per hectare) of conventional practice compared to organic practice. The second is chemical fertilizer cost, which covers about 20 percent additional cost (about $4.16 per hectare). Based on this information, we can predict the reduction of cultivation cost based on land use change of each scenario, which is presented in table 5.5.

Table 5.5 Total projection of cultivation cost reduction (unit: USD)

Scenario	2019	2025	2030	2035
BAU	1,945,172	3,604,732	3,604,732	3,604,732
S2	1,945,172	6,666,667	10,000,000	13,333,333
S3	1,945,172	16,666,667	33,333,333	50,000,000
S4	1,945,172	17,280,214	106,669,852	106,669,852

Moreover, the second different cost is from transferring cost of conventional to organic rice, which is land preparation cost to meet the requirement of organic standard. From our survey data, the farmers spent about $114.58 per ha on average for land preparation at the first time, switching area to organic production. Based on area change in each scenario, this cost is presented in the table 5.6.

Table 5.6 Total projection of transferring cost from conventional to organic rice (unit: USD)

Scenario	2019	2025	2030	2035
BAU	-	2,139,183	0	0
S2	-	3,666,667	3,666,667	3,666,667
S3	-	18,333,333	18,333,333	18,333,333
S4	-	29,000,230	179,016,899	0

Next, we move to yield prediction. Long-term crop yield estimations were predicted using the DNDC model over 2019-2035 under rice field management practices in rainfed systems. This model applies input data including climate, soil, crop, land and water management. Climate data included precipitation, minimum and maximum air temperatures projected over 2019-2035 from RU-CORE. Data on soil textures and properties were selected from relevant soil series data from rice planting areas obtained from the Land Development Department (LDD). Data on crop fertilizer for conventional rice fields was based on the amount and type of fertilizer recommended by the Rice Department. However, for organic rice fields, we applied data based on the average amount of fertilizer used by farmers obtained from our household survey. Both rice field management practices were assumed to apply the same soil preparation (land tillage) practices following the standard recommendations from the Rice Department, Thailand.

The yield prediction, considering the conventional rice fields, the average yield over 2019-2035 is 2.33 tons per ha per year (range from 2.16 to 2.82 tons per ha per year), while the average yield from the organic rice fields is 2.27 tons per ha per year (range from 1.98 to 2.73 tons per ha per year). The average yield from organic rice fields is slightly lower than from the conventional rice fields about 2.6%. Comparing between the fertilizer applied to conventional and organic rice fields, essential plant nutrients such as available N are applied more in conventional rice field than in organic rice fields. The high addition of nutrients results in higher yields.

Table 5.7 Projection of annual rice production from conventional and organic rice fields in the northeast of Thailand in each scenario (unit: Million tons)

Scenario	2019	2025	2030	2035
BAU	14.506	16.651	14.579	14.429
Scenario 2	14.506	16.650	14.516	14.430
Scenario 3	14.506	16.649	14.279	14.433
Scenario 4	14.506	16.649	13.726	14.436

6. Integrated Cost - Benefit analysis

In this section, the measures that can be quantified explained above, which are greenhouse gases emissions, biodiversity, health impact, rice yield, and cost of rice cultivation, are monetized to calculate benefits and costs generated under each scenario to identify the direct and indirect impacts (or externalities) of conventional and organic rice area changes. Note that the values generated from those measures under land use change of BAU scenario is used as reference to measure changes occurred in scenario 2, scenario 3, and scenario 4.

Our integrated benefit-cost analysis starts with three aspects. The first aspect is related to direct cost and revenue change, which focuses on measures that market values are available[68]. These measures include value of rice production, different cultivation cost between conventional and organic rice practices, and transferring cost from conventional to organic rice as shown in table 5.8. The second aspect represents the human health externality value, which covers public health cost from PM2.5 and value of farmer perception on risk of pesticide use in rice cultivation. Namely, value of statistical life (VSL) measured fatality risk reduction from pesticide poisoning estimated from choice experiment. The last aspect focused on environmental externality consisting with value of GHG emissions. Table 5.8 presents the details of measures included in each aspect. These three aspects mainly cover the impacts of an increase in organic rice area on direct revenue and cost, human health externality, and environmental externality.

[68] Result tables provide details of benefit-cost analysis in all aspects are in appendix 6.

Table 5.8 Measures included to different types of benefit-cost analysis

Issue	impact	Direct revenue and cost of rice production	Human health externality	Environmental Externality
Value of rice production	Revenue	✓		
Transferring cost of switching from conventional rice to organic rice	Cost	✓		
Cost reduction of changing from conventional rice to organic rice	Inputs Cost	✓		
Value of availability of beneficial insects	Pesticid e cost	✓		
Health cost reduction caused by PM2.5	Public health		✓	
VSL of fatality risk reduction from pesticide poisoning	Farmer health		✓	
Value of carbon for GHG emission from burning	GHG			✓
Value of carbon for GHG emissions from cultivation	GHG			✓
Value of carbon for soil carbon stocks	GHG			✓

The monetized values, which could be positive or negative, projected in each year for the next fifteen years, are summarized in terms of Net Present Value, using BAU as a reference. Therefore, net present values presented in scenario 2, scenario 3, and scenario 4 are the changes from the baseline projection according to BAU.

The main assumptions in this calculation are exchange rate, discount rate, and prices. The exchange rate is assumed to be 30 Baht for $1. The discount rate is based on Buncle et al. (2016), which is present a guide for analysis cost-benefit on the issue of natural resource management in the Pacific. A number of projects applied discount rates from 3 to 10 percent. Hence, in this study, we use the discount rates of 3 percent, 5 percent, and 8 percent. The main result showed only 5 percent discount rate, meanwhile the other results could be seen in the appendix. The monetary values per unit of factors are varied as shown in table 5.9. For the value of rice production, the price of rice conventionally produced is $328 per ton, which is the average price of rice from 1992 to 2020 (Bank of Thailand, 2020).

Data on production costs of conventional and organic rice were derived from the household survey, which showed that the average production cost of organic rice is about $20.83 per hectare lower than the average production cost of conventional rice. This saving is comprised of $4.16 from chemical fertilizer cost saving and $16.67 from pesticides cost saving. For the value of biological control, we use cultivation cost reduction of organic rice farming due to no pesticide cost. From our household survey, the average transferring cost for land preparation was reported to be around $114.58 per hectare for the first year of switching from conventional to organic practice.

The health cost from PM 2.5 is based on our calculation from health impacts analysis, as outlined in the fourth part of this report. The VSL value (value of statistical life) that farmers put on fatality risk reduction from pesticide poisoning calculated from choice experiment method is applied for health benefit due to no pesticide applied in organic rice field. The VSL value is $251.67 per hectare of organic rice.

Finally, the GHG emission value is computed by an average price of carbon credit from 2016-2020 reported by Thailand Greenhouse Gas Management Organization (2020). The average price of CDM carbon credit is $1.67 per ton[69]. Table 5.9 concludes the financial proxy for each measure[70].

Table 5.9 The monetary proxy per unit of factors

[69] Source of CDM carbon prices in Thailand are available at http://carbonmarket.tgo.or.th/index.php?lang=TH&mod=Y2hhcnQ=&action=bGlzdA== .

[70] The organic rice price and value of beneficial insects were subject to sensitivity analysis. In the case of organic rice, this included an assessment of 10 percent premium. Concerning the value of availability of beneficial insects, the monetary value estimated from choice experiment method, ($154.67 per hectare of organic rice) was subject to sensitivity analysis. The results are presented in appendix 5.

Variables	Monetary Proxy	Unit	Value USD
Rice output	Price	$/ton	328
Land conversion ("Transferring") cost	Cost	$/hectare	114.58
Organic production cost saving	Fertiliser Cost	$/hectare	4.16
Beneficial insects	Pesticide cost	$/hectare	16.67
Health cost from PM2.5	Health cost AHC	$/year	Cost
Fatality risk reduction from pesticide poisoning	Choice experiment VSL	$/ hectare	251.67
GHG emission	Carbon Price	$/ton CO2eq	1.67

6.1 Integrated Benefit-cost analysis: Direct revenue and cost of rice production

The direct impact analysis takes into account the cultivation cost and output value of rice and projects these values into the future based on each scenario compared to BAU scenario. Results are illustrated in Figure 5.1. The cultivation cost of organic practice is lower than that of conventional practice due to two main factors. The first is the cost saving from chemical fertilizer. The second factor is the benefit from natural pest management, which would decrease cost of pest management in rice fields. The expansion of organic rice area in scenarios 2, 3, and 4 therefore results in a reduction of cultivation cost, which results in positive net values ranging from $46 million to $437 million. The highest reduction of cultivation cost occurs in scenario 4 indicating the greater the area of organic rice the greater the cultivation cost reduction.

However, expansion of organic area creates some negative value to farmers in term of the first year transferring cost on land preparation and yield reduction. The negative transferring costs range from $34 to $350 million. While the values of rice production are also negative from $42 to $476 million.

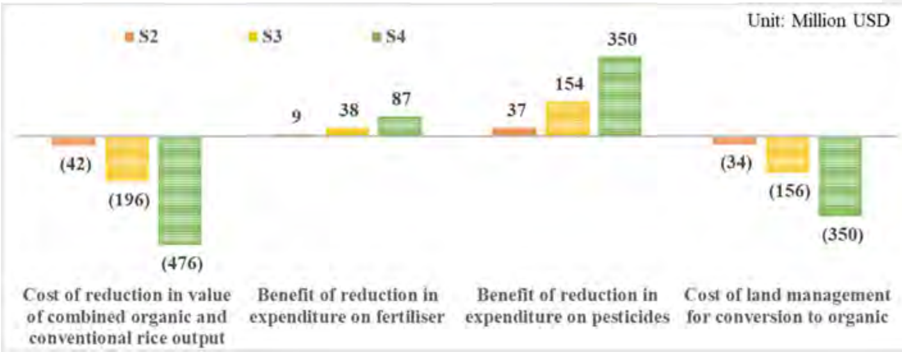


Figure 5.1 The total value of rice production and cost savings in each scenario from 2019 to 2035 compared to BAU.

Taking into account all of the additional cost and revenue from the expansion of organic rice area under scenarios 2, 3, and 4 comparing to BAU provides net negative value in terms of net present values (NPV). This is illustrated in figure 5.2 The highest negative NPV, $389 million, is represented in the fourth scenario, which contains the highest proportion of organic rice area. The negative NPV from 2019 to 2035 vis a vis BAU indicating that the reduction in rice cultivation cost associated with organic production is not sufficient to compensate for reduction of rice yield and the first year transferring cost on land preparation.

Figure 5.2 Financial analysis: Net present values projected from 2019 to 2035 in each scenario compared to BAU

However, the above analysis is concerned only with one type of economic issue in direct financial impact. As described earlier in this report, the TEEBAgriFood evaluation framework was developed to show that taking into account only financial aspects is insufficient as a basis to guide decision making for sustainable resource management, in particular in the agriculture and food sector (UNEP, 2018). The TEEBAgriFood analysis proposes a holistic economic assessment of value, that also takes into account the benefits and costs generated through changes in other externalities. In the following sections, the externalities of human health and environment are included into the economic assessment to arrive at a more complete, but still preliminary, assessment of the potential future value generated over the medium term by the expansion of organic rice production in the Northeast of Thailand according to the scenarios put forward.

6.2 Integrated benefit-cost analysis: Human health externality

A holistic economic assessment of value has to consider not only produced capital, but also additional costs and benefits that generate direct and indirect values. Human health externality, including the health and well-being of Thai people, are understood to have paramount importance in assessments of national health, but tend to be external to the economic forecasts adopted to develop the future of Thailand agriculture.

This section will summarize the assessed values of health effects that are generated in the production of organic and conventional rice. The health impacts are considered to health cost of particulate matter (PM2.5) reduction due to rice straw and stubble burning and VSL of fatality risk reduction from pesticide poisoning. Figure 5.3 presents the values' details of each issue under different scenarios. For the value of health cost reduction from decreasing PM2.5, scenario 4 provides the highest health cost reduction, $518 million, along 15 years compared to BAU. Meanwhile, the value of fatality risk reduction from pesticide poisoning is much higher in the fourth scenario, $3,628 million, due to the considerable increase in organic areas. The benefit gained from fatality risk reduction increases when organic rice area increase resulting less pesticide applied in rice fields, which would reduce fatality risk to farmers. This high value from farmers' perception could be implied that rice farmers do recognize the impact of pesticide use on their health. Moreover, this recognition is not just minor symptoms, but it is fatal impacts.

Figure 5.3 The values of health categorized by sources from 2019 to 2035 in each scenario compared to BAU

6.3 Integrated benefit-cost analysis: Environmental externality

The last aspect considers environmental externality, which includes the value of GHG emissions which encompass emissions from cultivation, rice straw burning, and soil carbon stock. Figure 5.4 presents the values of these issues compared to BAU. The results of the current analysis presented earlier indicate that when organic rice area increases the GHG emission from cultivation also increases. Projected over the period to 2035, the cost of GHG emissions that are generated from cultivation in the NE of Thailand range between \$2 million to \$24 million depending on organic rice area of scenarios 2, 3, and 4 compared to BAU. Scenario 4 projects the highest release of GHG emissions from rice cultivation followed by scenario 3 and scenario 2, respectively. However, when considering GHG emission from rice straw burning and soil carbon stock, the patterns are different from GHG emission from cultivation. This is because the GHG emission from rice straw burning decreases according to increase in organic rice area because burning rice field after harvesting is prohibited for organic rice practice. Scenario 4 provides the highest benefit of GHG emission reduction from rice straw burning, \$7 million, followed by scenario 3 and scenario 2 during 15 years, respectively. The pattern is also the same for soil carbon stock because an increase in organic rice area reveals an increase in soil carbon stock.

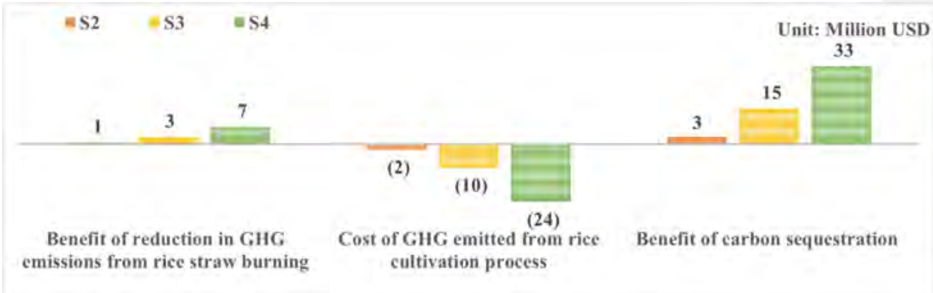


Figure 5.4 The values of GHG emissions categorized by sources from 2019 to 2035 in each scenario compared to BAU

6.4 Integrated analysis of all externalities

Considering only direct financial aspects such as cost and revenue, the more organic area, the more negative values. However, considering for externality from organic rice production, the organic practice could promote health and environmental externality, as presented in figure 5.5.

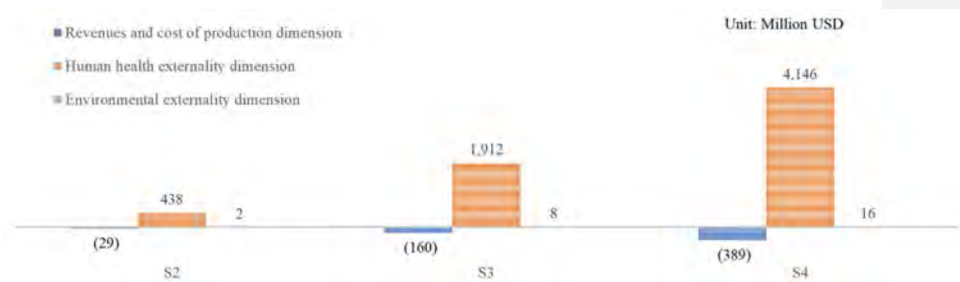


Figure 5.5 The positive and negative values of organic rice area expansion from 2019 to 2035 compared to BAU

From the integrated benefit-cost analysis, it could be concluded that switching from conventional to organic rice provides net gains in term of cost reduction, health cost reduction from PM 2.5 and fatality risk of pesticide poisoning, and lower overall GHG emissions. Meanwhile, the net negative impact would be from loss of rice yield. Overall, when financial aspect and externalities related to rice production are considered together, expanding of organic rice area induces positive net benefit to society as presented by Figure 5.6, which reveals that the higher the organic rice area the higher net benefit gained by society.

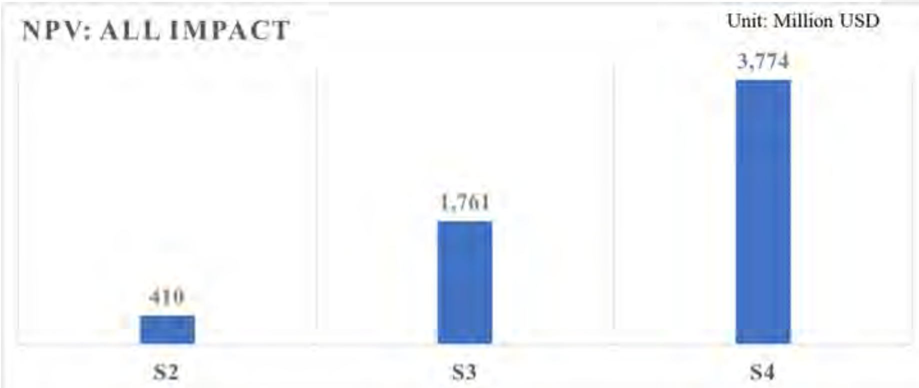


Figure 5.6 The net present value of organic area expansion from 2019 to 2035 in each scenario compared to BAU

Next we analyze the share of benefits and costs of expansion of organic rice area on related stakeholders. The impact on stakeholders from increasing organic rice area could be divided into two groups, rice farmers and the general public. Figure 5.7 showed that the rice farmers will receive net negative revenue from selling organic rice because the reduction in cost of production could not outweigh the loss of rice yield. Rice farmers, however, would benefit from health improvement due to less contact on pesticide poisoning due to expansion of organic rice area. Even though the benefit gained from health improvement is tremendously higher than loss caused by yield reduction, the loss of revenue from rice may be more salient to farmers than benefit gain from health risk reduction especially in the short run where their streaming of income is instantly affected and the benefit of health improvement may not be clearly presented yet.

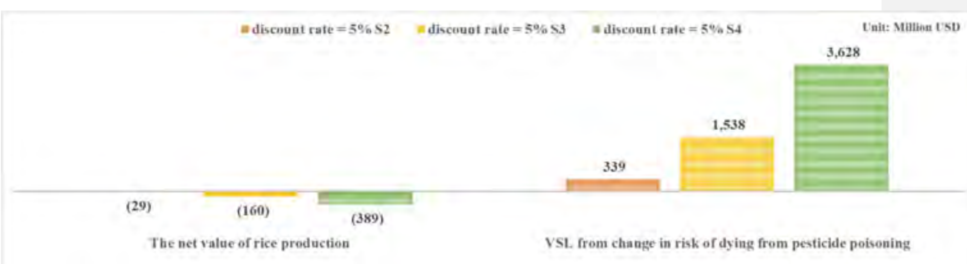


Figure 5.7 The value generated to farmers from organic rice area expansion from 2019 to 2035 in each scenario compared to BAU

The second group of stakeholders that would be affected by an expansion of organic rice area is general public. Figure 5.8 presents that public will receive net positive benefits from an expansion of organic rice area in two dimensions. The first benefit is from reduction of overall GHG emission from the rice sector. The more the area of organic rice is the lower of overall GHG emission from the rice sector. The second benefit gained by public when organic rice area is expanded is health benefit regarding to PM2.5 reduction. The reduction of PM2.5 results in lower cost of health problem due to air pollution.

Figure 5.8 The value generated to public from organic rice area expansion from 2019 to 2035 in each scenario compared to BAU

7. Scenario Analysis

The information of integrated benefit-cost analysis presented in previous section provides insightful information for the impact of organic rice area expansion on each issue and under each scenario. However, it may not be able to clearly visualize the big picture of trade-offs and synergies points that would be important for policy recommendation. Hence, we present the net changes occurred in each dimension under each scenario. Figure 5.9 presents radar chart that displays this result. The result shows that each scenario generates positive net benefit compared to BAU for almost all dimensions. Scenario 4 (S4), which contains the highest organic rice area, generates the highest overall net benefits. The main benefits generated from scenario 4 (S4) come from positive externalities that organic rice practice provides to society. These positive externalities include reduction of GHG emissions and health improvement through reductions of air pollution (PM2.5) and pesticide applied in rice fields.

However, scenario 4 (S4) reveals negative value for rice production when compared to BAU and also other scenarios (blue line that is lower than other lines for total value of rice production and the total transferring cost from conventional to organic rice). Given the price of organic rice was assumed to be the same as conventional rice under this analysis, this loss mainly comes from the significant loss of rice production under this scenario with vast increasing of organic rice area, about 88 percent of total rice cultivation area.

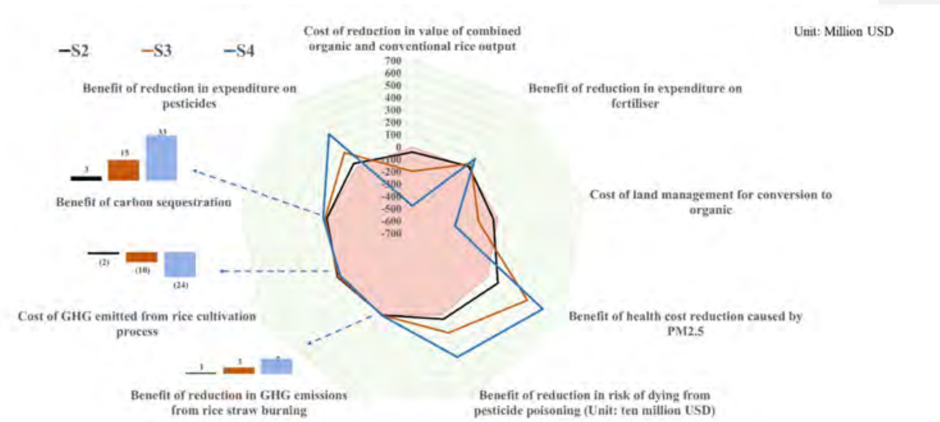


Figure 5.9 The scenario analysis based on values of all issue in each scenario compared to BAU

This negative effect directly affects rice farmers as it would reduce income of farmers when they switch to organic practice. If we want the situation that allows for maximizing benefits for environment and society with better well-being of farmers, the price of organic rice needs to be higher than conventional rice. Specifically, premium price of organic rice is necessary to fulfill the loss from yield reduction. We inflate the price of organic rice by 5 percent when compared to conventional rice. The effect of 5 percent premium price on value of rice production of each scenario compared to BAU is presented by Figure 5.10. It is clear that when the price of organic rice is just 5 percent higher than that of conventional rice the net present value of rice production turn to positive especially for scenario 4. The net value of rice production changes from -389 million USD to 745 million USD in this scenario, which is the highest among other scenarios. If this case is possible, scenario 4 (S4) will be the best scenario showing that an expansion of organic rice area for almost entire rice cultivation area in the Northeast region of Thailand provides not only positive externalities to society but also generates better well-being to rice farmers.

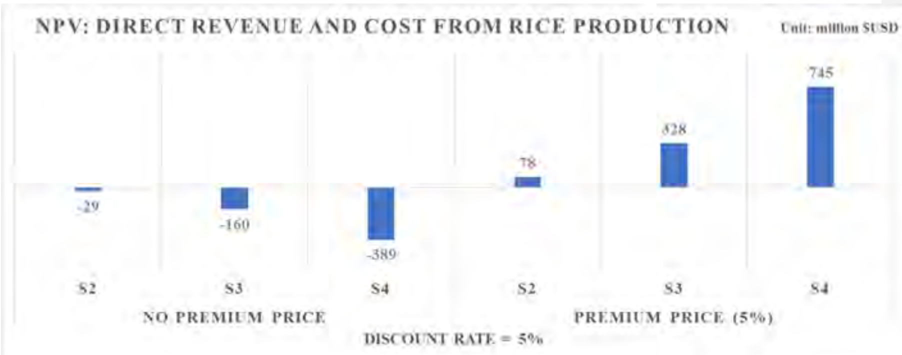


Figure 5.10. The net revenue from organic production without premium price and with 5% premium price from 2019 to 2035 in each scenario relative to BAU

8. Conclusions

This study reveals broader conclusions on the possible visible and invisible costs and benefits of conventional and organic rice productions at the landscape level. These costs and benefits can be categorized into direct effect and externality. The issues under direct effect consists of rice yield and cost of cultivation. While the externality covers the issues of GHG emission, biodiversity, and human health impact caused by air pollution and pesticides. Integrated benefit-cost analysis and scenario analysis are employed to identify trade-offs and synergies solutions that could maximize benefits and minimize costs. This information is very important and mandatory if we want to inform policymakers.

We found trade-off situation from some issues. The first one is GHG emission from cultivation. Expansion of organic rice area is projected to induce more GHG emission from cultivation when compared to conventional rice practice. However, the GHG emission from organic cultivation would completely be offset by reduction of GHG emission from rice straw burning and ability to increase soil carbon stock when compared to conventional rice practice. The second trade-off is between rice yield and the cost of cultivation. Expansion of organic rice areas would reduce the cost of rice cultivation, but there will be a decrease in rice yield.

Due to trade-offs availability, scenario analysis based on varying conventional and organic rice cultivation areas would shed light on opportunities for solutions that would provide the highest benefit to society with better well-being of farmers. The results of scenario analysis clearly present that the highest net benefit is generated from scenario 4 (S4) where almost 90 percent of rice cultivation in the Northeast region of Thailand is converted to organic practice. The main benefit occurred in this scenario comes from positive externalities generated from organic rice practice. These externalities include reductions of GHG emissions, human health impact caused by air pollution and pesticides. In addition, the organic practice also generates direct benefit to farmers through cultivation cost reduction due to improvement of biodiversity. However, the cultivation cost reduction cannot outweigh the loss from yield reduction resulting net loss from rice production in scenario 4 (S4). Even though all positive externality is tremendously larger than loss from rice production in this scenario. We need to keep in mind that the loss from rice production is directly impact farmers and would reduce their well-being through income loss. To cope with this situation, the price of organic should be higher than that of conventional rice. From our calculation, the premium price of organic rice, which is at least about 3 percent higher than that of conventional rice, would be enough to turn the negative return of rice production from yield loss to positive return. Note that currently the price of organic rice in Thailand is on average about 15-20 percent higher than that of conventional rice. However, if the supply of organic rice increases as the situation of scenario 4 (S4) it would be possible that organic farmers may not be able to get premium price for organic rice anymore. If this is the case, price subsidy or income subsidy for organic farmers may be necessary to return and reflect the positive externalities generated by organic farmers to society.

In addition to scenario analysis, this study also identifies who is affected by each issue due to different rice practices. Expansion of organic rice areas would induce more public benefits via reduction of GHG emission, health impact from PM2.5, and improvement of biodiversity. For farmers, switching to organic rice practice generates private benefits to rice farmers in two issues, reductions of cultivation cost and health impact from pesticides. However, it also imposes a private cost to farmers by yield reduction and one time cost of preparing land for organic practice. The cultivation cost reduction can completely offset the cost of preparing land but cannot completely offset the loss of yield resulting in less profit per hectare given the price of organic rice is the same as conventional rice. However, the total benefit gained by farmers from switching to organic rice practice is still positive as the health benefit totally outweighs the loss of profit.

All in all, public and private benefits generated from an increase in organic rice areas are positive. However, we need to seriously keep in mind that the decision to adopt the organic rice practice mainly depends on farmers. The loss of revenue due to yield reduction and upfront cost for land preparation would be very salient when compared to the farmers' health benefits, which would not be visible in the short run for farmers. To influence them to change from conventional practice to organic practice, policymakers need to consider forms of interventions that could shoulder any transition costs for farmers to the new practice. This issue is explored in the next part, Part 6, where we test types of interventions that may be able to induce more farmers to adopt organic rice practice.

Part 6: Analysis of Potential Interventions to Enhance Organic Adoption

1. Introduction

Part 4 of this report presented the findings of the analysis that indicate that organic rice practice generates better benefits for both private and public benefits in various dimensions when compared to conventional rice practice, and Part 5 summarized the forecast benefits according to the adoption of four alternative future scenarios. In this Part, we explore and analyse potential interventions that may enhance the adoption of organic agriculture in the Northeast of Thailand.

Adopting organic rice practice requires immediate additional investments such as labor, machinery, and organic fertilizer. In addition, according to the household survey information, farmers may be concerned about the loss of yield especially during the early period of converting from conventional practice to organic practice. They may be therefore unwilling to bear these up-front costs for an uncertain future gain resulting in low rate of adopting organic rice practice even when long-term benefits of organic rice practice outperform conventional counterpart. In this chapter, we present the study from a lab-in-the-field experiment that was conducted with conventional and organic rice farmers in the Northeast region of Thailand to test two potential strategies to increase the rate of adopting organic practice. The potential strategies include temporary short-run incentives in two forms, cost subsidy and income subsidy, and social learning through information provided by different types of role model farmers.

If the private returns of converting from conventional rice to organic rice practice are negative in the short term but positive in the long term, one possible way to increase adoption would be to offer temporary incentives conditional on adopting and maintaining organic rice practice. Theoretically, incentives should persuade farmers to adopt the new practice if the incentives are large enough and could mitigate risk especially during early adoption (Ambler et. al, 2020). In addition, the forms of incentives would also be important because people seem to respond differently to different forms of incentives even when the values of incentives are the same (Gneezy et al, 2011). From 2017-2020, Thailand government employed cost subsidy to incentivize farmers to adopt organic rice practice under One Million Rai Program. Under this program, farmers receive a three-year cost subsidy if they adopt organic rice practice. However, there is another form of subsidy, income subsidy, that may be able to induce more farmers to adopt organic rice practice given the same amount of subsidy provided. This may be because the income subsidy would provide psychological effect as its mechanism directly generates certain income for farmers if they adopt organic rice practice, while the cost subsidy cannot. If this hypothesis is true, given the same amount and time of subsidy, income subsidy may be more attractive to farmers than cost subsidy as the farmers know that their income is secured. In this study, we therefore try to test whether the different forms of subsidies, which are subsidy for production cost and subsidy for income, generate different effects on organic rice practice adoption.

In addition to subsidy, we examine the influence of information diffusion through learning from farmers to farmers on the adoption of organic rice practice. Specifically, we investigated whether farmers learn from peer farmers in deciding for oneself could be through the transmission of knowledge or of information about the behavior of others that can be imitated. Learning could be induced as farmers tend to learn more from farmers than from community leaders and extension staffs (Mobius and Rosenblat, 2014; Benyishay and Mobarak, 2019). Further, there is anecdotal evidence suggesting that farmers may observe and imitate the decision of farmers who share similar conditions that are comparable to the conditions facing them (Attavanich et al, 2019). We therefore design to test whether we can improve organic rice adoption through social learning by involving farmers closer to various types of other farmers who are set as organic rice promoters. This could help us in shaping the program and intervention recommendation on the type of farmers to be selected as promoters of organic practice through the social learning process, which already exists in rice farming community.

2. Methodology

To answer the research questions ["do farmers..."], a lab-in-the-field experiment is designed to observe farmer's decisions of choosing between two cultivation methods, conventional rice practice and organic rice practice. The experiment is conducted in rice farming communities in Khon Kaen, Buriram and Surin provinces, which are located in the Northeast region of Thailand. In the experiment setting, the two cultivation methods incur costs and return in different ways. Cost of cultivation and return of conventional rice are fixed for every round of experiment, representing cropping seasons. The return is barely higher than cost of cultivation to mimic the real situation of conventional rice where the price is low. Meanwhile, the organic rice farming contains higher cultivation cost than conventional one and the return in the first three rounds of experiment is set to be lower than the cost to imitate the actual practice for planting organic rice, which needs time to improve soil fertility during the early stage of adoption. After that, the yield will increase to almost the same as conventional rice resulting in higher profit as the higher price by the demand of high quality for organic rice.

Specifically, in the experiment setting, the cost of cultivation of conventional rice is 6 Baht/Rai and cost of growing organic rice is 8 Baht/Rai. The return of conventional practice is consistently assumed to be 8 Baht/Rai for all rounds (seasons). The return of organic method, on the other hand, is 5 Baht/Rai in the first three rounds (seasons), which represents the low-yield during the early of transformation. However, the return of organic practice increases to 12 Baht/Rai in the fourth rounds onward represented an increase of yield after soil fertility is improved.

In addition to cost and return of cultivation the 20 percent risk of losing some yields is assumed in both cultivation methods as uncontrollable damage such as drought and flood. Practically, when it occurs, the return of conventional practice drops from 8 Baht/Rai to 4.8 Baht/Rai, while the return of organic practice drops from 5 Baht/Rai to 1.5 Baht/Rai for the first three rounds (seasons) of adopting organic practice and from 12 Baht/Rai to 7.2 Baht/Rai since the fourth round (season) of continuously choosing this practice. Note that if there is any switching back from organic practice to conventional practice, the cost and the return of organic practice are reset. The experiment is set to ten rounds as ten seasonal cropping. In each round, participant farmers are asked to choose what practice they design to invest. To motivate participants to seriously consider what practice they will choose in each round, the net profit occurred in the experiment is exchange to real money and pay to participants. Given ten rounds (seasons), without any interventions with the conditions of investment and return in the experiment, the rational participants are assumed to continuously choose conventional practice for all ten rounds to maximize the highest profit as the best strategy when compared to organic practice. Table 6.1 presents the net return of each method from rounds 1-10.

Table. 6.1 The possible of highest payoff of two methods.

Condition	Method I	Method II
1^{st} -3^{rd}		
Cost (Baht/ Rai)	6	8
Return (Baht/ Rai)	8	5
Highest payoff (Bath/ Rai)	+6	-9
4^{th} -10^{th}		
Cost (Baht/ Rai)	6	8
Return (Baht/ Rai)	8	12
Highest payoff (Bath/ Rai)	+14	+28
Total ten rounds (Bath/ Rai)	+20	+19

The implementation

The experiment was set up at the center of each village. Before the experiment started, participants are asked to answer a short questionnaire. After finishing the questionnaire, the experimenters start to encourage participants by introducing a scope of activities, then lead them to watch a video clip that explains the steps and process of investment of two practices in the experiment. The video clip consists of the conditions of investment, the cost and the return, and the payoff computation. Moreover, to diminish the misunderstanding, participants are allowed to play two example rounds to amend the process of investment in the experiment.

Initially, participants have endowments as a proxy of their economic status in the experiment consisting on land, savings, and debt. To avoid copying answers, participants are asked to randomly select an equipment box by themselves, and no one knows other endowments in the boxes, although all the boxes have the same endowments. A box consists of a card of ten rai of land for planting (about 1.6 hectare), a card of 120 Baht for debt invoice, and 100 Baht in virtual money. Figure 6.1 provides an illustration of the box.

The experiment is run for ten rounds totally, in each round, after the experimenter announced a round number, the participants are asked to choose what practice between organic and conventional practices they are going to invest for such round. The cost and return between two practices are always shown on the screen during experiment to help them recall the cost and return of both practices before making decision. Note that they could choose only one method and have to invest in all ten rai of lands in each round.

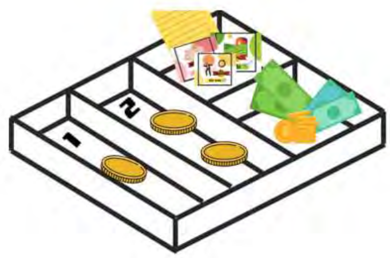


Figure 6.1. Example of an endowment box.

In each round, after participants have finished the investment, the sub box is collected by our staff to control for computing the return and to prevent cheating. The experimenter then begins to bring a black box that contains 10 balls for participants to draw a ball. This step is to determine the effect of uncontrollable factors for losing some yield in each round. According to the probability of uncontrollable factors is 20 percent so the black box has two orange balls for the losing case and eight white balls for neutral case.

As the consequence, the participants have 10 rai for planting rice, so the cost and the return are multiplied by 10. For conventional rice practice, the cost of investment per rai is 6 Baht while the return is 8 Baht/Rai in neutral situation and is 4.8 Baht/Rai in losing case, so the net payoff of each case is as follows

- Neutral case: return (8*10)- cost (6*10) = 80 – 60 = 20 Baht.
- Losing case; return (4.8*10) – cost (6*10) = 48 - 60 = -12 Baht.

Meanwhile, for the organic practice, the cost is 8 Baht/Rai, and the return for the neutral situation is 5 Baht/Rai in the first three rounds and 12 Baht/Rai since the fourth round. Besides, in the losing case, the return drops from 5 Baht/Rai to 1.5 and from 12 Baht/Rai to 7.2 Baht/Rai respectively so the net payoff of each case is as follows

- Neutral case for first three rounds: return (5*10)- cost (8*10) = - 30 Baht.
- Neutral case for since fourth round: return (12*10)- cost (8*10) = 40 Baht.
- Losing case for first three rounds: return (1.5*10)- cost (8*10) = -

65 Baht.

- Losing case for since fourth round: return (7.2*10)- cost (8*10) = -8 Baht.

Without any interventions, the best possible outcomes for ten rounds is to continue choosing conventional rice practice, which provides higher payoff than organic rice practice because the net highest payoff of conventional rice practice is 200 Baht (20*10), while the net highest payoff of organic rice practice is 190 Baht ((3*-30) + (7*40)). Hence, without any interventions, it would be more likely that the conventional practice would have higher chance to be selected by participant farmers.

Interventions and extra conditions for the treatment groups.

As mentioned earlier, we are interested in the impact of subsidy and social learning interventions to promote organic rice adoption. We develop details of each intervention that is highlighted as follows.

Cost and income subsidies

Two types of subsidies are used to motivate participants to organic practice. The first type of subsidy is cost subsidy. Whenever participants adopt organic practice within the first three rounds, they are given 5 Baht per rai to compensate the cost so the compensation for the participants who choose organic practice since the first round is 15 Baht/rai, 10 Baht/rai for those who switch in the second round, and 5 Baht/rai for those who switch in the third round. There is no subsidy for those who switch to organic rice in the fourth round and onward.

The second type of subsidy is income subsidy. Instead of compensating cultivation cost, participants in this group are guaranteed to get an additional return of 5 Baht/Rai within the first three rounds, which is the same amount as the cost subsidy. Technically, farmers should make the decision in the same direction if they receive the same amount of subsidy. However, different forms of subsidies may differently affect decision even if the amounts of subsidies are the same and, especially if psychological effects are different between these types of subsidies.

Role model information

In the rural of Thailand, government tries to enhance new technology adoption in agriculture to improve productivity. One possible strategy, which may have better cost-effectiveness than subsidy, is to create role model farmers in each community in hope of speeding up imitation. In the context of rice, the benefit from the organic rice in the long run is absolutely better than conventional rice, which makes the benefit in terms of the financial, health, and environments. etc. As a consequence, farmers should follow the role models and switch from conventional rice to the organic rice to get the higher benefit from their crop. However, general farmers may ignore and may not imitate the role models especially if they perceive conditions faced by role model farmer and their are different. Thus, to test the hypotheses, the different economic status of the role models is varied by the endowments, land, saving, and debt. Namely, there are three types of role model farmers who differ in the level of endowments, which are higher endowments, lower endowments, and equal endowments compared to participant farmers. All types of role model farmers design to choose only the organic method and frame as the one who has the highest payoff from the experiment. The role model's endowments and decision are shown to participants in each round prior participants make decision of what practice they will choose in such round.

Interventions and treatment groups

From details of each intervention, we create treatment groups to identify their effects. The decision made by participants in treatment groups, which undergo various interventions, is compared to decision made by participants in the control group where no intervention is employed. Since we have two forms of subsidies, cost and income subsidies, and information provided by different role model farmers, the same endowment, lower endowment, and higher endowment, five treatment groups and one control group are established to directly test their impacts. The details of each treatment group are as follows.

First, a group that ran with no intervention is called a control group (C). The second group is the group that has a cost subsidy for participants to encourage them to choose organic rice. This group is called treatment 1 (T1). Third is a group with income subsidy. Participants in this group is guarunteed income as the income subsidy. This group is called treatment 2 (T2). Fourth to sixth experimental groups are ones to test the information from different types of role model farmers. The information from the role model farmer with the same endowment as participants is added in a group called treatment 3 (T3). While, the treatment with information of role model farmer with lower endowment than participant farmers is a group called treatment 4 (T4). The last treatment is a group that receives information from the role model farmer with higher endowments than them, and this group is called treatment 5 (T5). Table 6.2 presents the information of interventions for experimental groups.

Table 6.2. Details of interventions for each experimental group

Experimental group	Subsidy		Types of role model farmer		
	Cost	Income	Same endowment	Lower endowment	Higher endowment
C	-	-	-	-	-
T1	✓				
T2		✓			
T3			✓		
T4				✓	
T5					✓

3. Data and Estimation

Sample

Our sample consists of conventional and organic rice farmers from three provinces in the Northeast region of Thailand. We contacted village heads that we already conducted household survey to ask them to help contacting ten rice farmers who were chosen by us to be participants in this experiment. Those who refused to participate were replaced by substituted samples drawn by us. After getting the completed list of the samples, the field team contacted the headman in each village to make appointments with them**.** As the interventions are developed to induce conventional rice farmers to adopt organic rice practice, the majority of our sample therefore is conventional rice farmers. Table 6.3 presents the details of participant farmers categorized by provinces and types of farmers.

Table 6.3 Participant farmers categorized by provinces and types of farmers

Province	Conventional farmer	Organic farmer	Total
Buriram	170	30	200
Khon Kaen	140	60	200
Surin	130	70	200
Total	440	160	600

Note that the randomization unit is at village level where all participants in the same village are assigned to the same experimental group. We randomly assigned each village to one of experimental groups stratified by provinces. Table 6.4 presents the result of random assignment.

Table 6.4 Number of samples based on random assignment

Experimental group	Buriram		Khon Kaen		Surin		
	Conventional farmer	Organic farmer	Conventional farmer	Organic farmer	Conventional farmer	Organic farmer	Total
C	20	0	30	20	30	0	100
T1	10	20	20	10	10	30	100
T2	30	10	10	10	40	0	100
T3	20	0	20	20	20	20	100
T4	50	0	30	0	0	20	100
T5	40	0	30	0	30	0	100
Total	170	30	140	60	130	70	600

Empirical Strategy

To evaluate the impacts of interventions on organic rice practice adoption in the experiment, we estimate two sets of specifications using regressions at the participant level. Our first set of specification focuses on analyzing data from organic and conventional farmers. Since the data obtained from the lab-in-the-field experiment has multilevel or clustered structure due to the longitudinal nature, an approach used to analyze such clustered data is the use of random effect regression analysis. Provided that the outcome variable in this study is a decision whether to adopt organic rice practice or conventional rice practice, the outcome variable is in a dichotomized manner or considered as a binary outcome. Thus, a random effect probit model is applied to estimate all model specifications described further. The first model of this specification focuses on analyzing all treatments together. The model specification for this purpose can be presented as follows:

$$Dc_{it} = \alpha + \beta_1 SC_i + \beta_2 SI_i + \beta_3 PE_i + \beta_4 PL_i + \beta_5 PH_i + \gamma Rl_{it} + \boldsymbol{\beta}\mathbf{X_i} + \varepsilon_i \qquad (6.1)$$

where Dc_{it} is decision of a farmer *i* at round *t*. It is equal 1 if a farmer selects organic rice practice and 0 otherwise. SC_i, SI_i, PE_i, PL_i, and PH_i represent dummy variables of subsidy cost treatment, subsidy income treatment, information from role model farmer with the same endowment treatment, information from role model farmer with lower endowments treatment, and information from role model farmer with higher endowment treatment, respectively. Note that decision made by participants in control group is used as reference in estimation and this is applied to all specification explained below. Rl_{it} is a variable represented outcome of losing some yield of farmer *i* at round *t*. Rl_{it} is equal to 1 if the orange ball is drawn meaning that farmers lose some yield in that round, and 0 otherwise. $\mathbf{X_i}$ is a vector of control variables represented farmers' characteristics and province alternative specific constant where Surin province is used as reference.

The second model of this specification is to test whether the short-run effects of cost subsidy and income subsidy on enhancing organic rice adoption are different or not. To test the short-run effects of these forms of subsidies, we restrict our analysis for the decision made in the first three rounds of cost subsidy and income subsidy treatments as the subsidies are only available for the first three rounds of experiment. The model specification to test the short-run effects of subsidies is as follows:

$$Dc_{it} = \alpha + \beta_1 SC_i + \beta_2 SI_i + \gamma Rl_{it} + \boldsymbol{\beta}\mathbf{X_i} + \varepsilon_i \qquad (6.2)$$

where *t* = 1, 2, 3.

The third model of this specification is to test whether the long-run effects of cost subsidy and income subsidy are different. After the third round of experiment, both subsidies are not available any more to farmers. It is possible that farmers may convert to conventional rice practice after the subsidies are ended especially those in subsidy cost treatment as the cost of practicing organic rice is higher than conventional counterpart. To answer to this question, the model specification is the same as equation 6.2 but the data used to estimate this effect is from round 4 to round 10 of both treatments where both subsidies are not available for farmers. The model specification for this test is as follows:

$$Dc_{it} = \alpha + \beta_1 SC_i + \beta_2 SI_i + \gamma Rl_{it} + \mathbf{\beta X_i} + \varepsilon_i \quad (6.3)$$

where t = 4, 5, 6,…, 10.

The fourth model of this specification highlights the short-run effects of information provided by different types of role model farmers. Since the three types of role model farmers, same endowment as participants, lower endowment than participants, and higher endowment than participants, adopt organic rice practice in the first round of experiment, they take risk of losing income in the first three rounds (seasons). If participants adopt organic rice practice in one of the first three rounds of experiment, it would suggests that information from role model farmers would strongly affect their decision. In order to analyze these impacts on enhancing organic rice adoption, we conducted an analysis only those in role model farmer information treatments for the decision made in the first three rounds of experiment. The model to test this question is presented below:

$$Dc_{it} = \alpha + \beta_3 PE_i + \beta_4 PL_i + \beta_5 PH_i + \gamma Rl_{it} + \mathbf{\beta X_i} + \varepsilon_i \quad (6.4)$$

where t = 1, 2, 3.

The final model of this specification focuses on the long-run effects of information provided by different types of role model farmers. To test clarify these effects, we analyze data from those in role model farmer information treatments for the decision made in the round 4 to round 10 experiment. The model of this test is as follows:

$$Dc_{it} = \alpha + \beta_3 PE_i + \beta_4 PL_i + \beta_5 PH_i + \gamma Rl_{it} + \mathbf{\beta X_i} + \varepsilon_i \quad (6.5)$$

where t = 4, 5, 6,…, 10.

The second set of specification focuses specifically on conventional farmer samples. This is because the conventional farmers would be the main target of these interventions. In addition, they may response to these interventions differently when compared to organic rice farmers. To answer whether these interventions could incentivize conventional farmers to adopt organic rice practice, the analysis of this specification highlights on decision made by conventional rice farmers. Namely, we use data from conventional rice farmers only to analyze the impacts of these interventions. The strategy to analyze the data is the same as those for the first set of specification. Therefore, the equations applied to analyze impacts of interventions for conventional farmers are the same as those presented in equation 6.1-6.5.

4 Results

First, we present the estimation results from entire samples, which include both conventional and organic rice farmers. Table 6.5 presents the results from entire samples following model specifications 6.1 to 6.6. The full model column reveals the results of all interventions on farmers' decision whether to adopt organic rice practice. Note that decision made by farmers in the control group is used as reference. The results of the full model suggest that both types of subsidies, cost and income, would be able to incentivize farmers to adopt organic rice practice because the coefficients of cost subsidy (Cost) and income subsidy (Income) are positively and statistically significant indicating that farmers who are in cost subsidy treatment and income subsidy treatment are more likely to adopt organic practice than farmers in control group where both forms of subsidies are not available.

The next intervention is information from role model farmers, which can be separated to three types depending on characteristics of role model farmers. Generally, providing decision information of role model farmers would enhance organic rice adoption because all three coefficients of role model farmers (Same endowment, Low endowment, and High endowment) are positively and statistically significant suggesting that farmers in these treatments tend likely to adopt organic rice practice more than farmers in the control group. We then test whether the impact of information from different types of role model farmers has different impacts on convincing farmers to adopt organic rice practice. It is possible that farmers may be most convinced by the advice of others who share similar or the same characteristics to them. To answer this question, we test whether the coefficients of Same endowment, Low endowment, and High endowment variables are different or not. The test results reveal that the coefficient of Same endowment, which represents the impact of information from role model farmer with the same level of endowment as participant farmers, is statistically significantly larger than those of Low endowment and High endowment variables. The test also indicates that the coefficients of Low endowment and High endowment variable are statistically insignificant different. The test results first suggest that information provided by role model farmer who shares the same level of endowments as the participant farmers seems to have more impact for convincing participant farmers to adopt organic rice than when role model farmers have different level of endowments. Second, information provided by either role model farmer with lower endowments than participant farmers or role model farmer with higher endowments than participant farmers seem to have the same effect on decision to adopt organic rice practice. Given the information provided by role model farmers would increase organic rice adoption, our results suggest that farmers appear to be the most convinced by the advice provided by role model farmers who share the same characteristics as them.

For farmer's characteristics, the results from full model column indicate that gender and age of farmers affect decision to adopt organic practice. Male farmer seems likely not to adopt organic farming compared to female farmer. Young farmers would more likely to adopt organic practice than old farmers. Participant farmers who already practice organic rice farming are more likely to adopt organic practice in experiment than conventional farmers.

Short run and long run effects of cost and income subsidies

Next, we turn to the results of testing short-run and long-run effects of subsidies. Column "Short-run effect of subsidies" presents the result of model specification 6.2 where data occurred in round 1-3 in experiment is employed for estimation. This specification aims to answer whether the effects of cost subsidy and income subsidy are different in the first three rounds of experiment where both subsidies are available to farmers who adopt organic rice practice. The results show that the coefficients of Cost and Income variables are positive and statistically significant and the size of both coefficients are statistically significantly larger than those in the Full model specification suggesting the impacts of both subsidies on convincing farmers to adopt organic practice are more intense in the short-run. We then test the size of cost subsidy coefficient and income subsidy coefficient to check whether they are different from each other. Our test result indicates that even the coefficient of cost subsidy seems to be a bit smaller than that of income subsidy, they are not statistically different (p-value>0.10) suggesting that both forms of subsidies provided the same effect for persuading farmers to adopt organic practice in the short run.

We next move to the long-run effect of these subsidies where data from round 4-10 of experiment are used. Note that starting from round 4 there are no subsidies for organic rice practice available for farmers anymore. However, farmers are still freely allowed to choose what types of practices, conventional and organic practices, they want to choose in each round. The results of this test are presented in the column "Long-run effect of subsidies". First, the results show that the effects of both forms of subsidies are reduced in the long-run as their coefficients are statistically significant smaller than those of short-run effect. It is not a surprise result as mentioned earlier that from rounds 4 -10 there are no subsidies available, and farmers who do not adopt organic practice in the first three rounds may be reluctant to change to organic practice as no subsidy available to mitigate the risks. We then test the coefficients of cost subsidy and income subsidy on organic adoption. The test result suggests that the coefficient of income subsidy is significantly larger than that of cost subsidy (p-value<0.05). This means that income subsidy has better long-run effect on organic rice adoption than cost subsidy after the subsidies are removed. The main reason of this result would be the fact that some farmers in subsidy cost treatment who already adopted organic practice in the first three round may switch back to conventional practice because when the cost subsidy ended in the third round they need to pay the full cost of growing organic rice by themselves, which is significantly higher than that of conventional practice. This may create a psychological effect as farmers may see the instant increase in cost as a loss. On the other hand, farmers in income subsidy treatment may not feel at the same way because they may already get used to the high cost of organic practice as they pay the full amount of cost by themselves since the start of adopting organic rice. In addition, the return from organic rice practice is higher than that of conventional practice after third rounds (seasons) of adoption with income subsidy of continuing growing organic rice. Thus, they would feel no loss when the subsidy ends, and continue focusing on the return generated from organic rice. The results of short-run and long-run effects of cost subsidy and income subsidy could provide policy suggestion. Given the same values of subsidies even both forms of subsidies would be able to equally convince farmers to adopt organic practice in the short-run, income subsidy would be better in term of keeping them to stay with organic practice after the subsidies are removed.

Short run and long run effects of different types of role model farmers

We also test the short-run and long-run effects of social influence to promote organic rice practice. This intervention is based on social learning from different types of role model farmers. Role model farmers act as communicators who provide information about how they made decisions on organic rice adoption. For our experiment, all types of role model farmers adopt organic rice in the first round of experiment and continue to the end of experiment. This means that they get negative return since the experiment started, and will have chances to regain positive return in the round 4-10. If participant farmers use information and follow advice from role model farmers, they should adopt organic practice as early as them. To test this, we restrict our estimation for the short-run impact of information provided by role model farmers on organic rice adoption from rounds 1- 3 of experiment. The results of this specification are presented in the column "Short-run effect of social learning". The results clearly show that first the impacts of all types of role model farmers seem to be larger than what we have in the "Full model" indicating that in the short-run information provided by role model farmers would be able to advice farmers to adopt organic practice. When we consider information provided from what type of role model farmers would be the most effective to convince farmers to adopt organic practice, the result suggests that role model farmer with the same endowments as participant farmers is the one whose information is the most effective to persuade participant farmers to choose organic practice. The information provided by role model farmers with higher or lower endowments seems to have the same impact for enhancing organic adoption.

We also found the similar results from long-run effect of social learning, represented by the column "Long-run effect of social learning", on organic rice adoption. Information provided by role model farmer with the same endowments as participant farmers is still the most effective information to convince farmers to adopt organic practice. From the short-run and long-run results of social learning treatment, it is clear that a role model farmer who shares the similar or the same characteristics (in our study endowments) as general farmers would generate greater diffusion of organic adoption among target farmers than those with different characteristics.

Table 6.5 Full data estimation results

Variables	Full model	Short-run effect of subsidies	Long-run effect of subsidies	Short-run effect of social learning	Long-run effect of social learning
Subsidies					
Cost	3.221***	6.982***	3.171***		
	(0.000)	(0.000)	(0.000)		
Income	4.286***	7.878***	4.810***		
	(0.000)	(0.000)	(0.000)		
Role model farmers					
Same endowment	3.390***			5.658***	2.644***
	(0.000)			(0.000)	(0.000)
Low endowment	1.952***			3.842***	1.434***
	(0.000)			(0.000)	(0.000)
High endowment	2.090***			4.414***	1.706***
	(0.000)			(0.000)	(0.000)
Orange ball	-0.167	-0.445	-0.269	0.169	-0.259
	(0.208)	(0.224)	(0.298)	(0.584)	(0.186)
Gender	-0.490***	-0.342	-0.015	-0.663	-0.199
	(0.005)	(0.496)	(0.953)	(0.125)	(0.296)
Age	-0.043***	-0.049**	-0.031**	-0.062***	-0.027***
	(0.000)	(0.043)	(0.014)	(0.004)	(0.004)
Organic farmer	1.949***	2.061***	1.669***	3.603***	1.871***
	(0.000)	(0.001)	(0.000)	(0.000)	(0.000)
Size of land	-0.005	0.000	-0.009	-0.026*	-0.013*
	(0.441)	(0.990)	(0.367)	(0.087)	(0.086)
Ln(income)	-0.034	-0.640**	-0.589***	0.178	0.032
	(0.642)	(0.023)	(0.000)	(0.295)	(0.659)
Khon Kaen	-0.569***	-1.091*	-1.147***	-0.004	-0.072
	(0.006)	(0.065)	(0.000)	(0.994)	(0.731)
Buriram	1.207***	-0.712	-0.365	3.181***	2.422***
	(0.000)	(0.244)	(0.295)	(0.000)	(0.000)
Constant	2.738***	9.344**	8.999***	-0.443	0.631
	(0.008)	(0.012)	(0.000)	(0.862)	(0.555)
Log likelihood	-783.260	-234.028	-227.439	-387.359	-371.871
Observation	6,000	900	2,100	1,200	2,800
Individual	600	300	300	400	400

Note: Numbers in parentheses are p-value. ***, **, and * are significant level at 1%, 5%, and 10%, respectively.

We also estimate the equation presented in table 6.5 using only data from conventional farmers to test whether these interventions could be able to incentivize conventional farmers as they do in the full data specification. The results of this specification are presented in table 6.6. The results from table 6.6 clearly confirm that the findings we have from the full data specification are still strongly valid with conventional rice farmers. The results also suggest that both cost and income subsidies are very important for conventional farmers especially in the short-run as the coefficients of these subsidies are significantly larger than those in the full model specification (please see column "Short-run effect of subsidies" in table 6.5and table 6.6). For the information provided by role model farmers, the results still reveal the same story as full data specification. Conventional farmers would likely to follow information advised by a role model farmer who has the same characteristics (endowments) more than those with different characteristics.

Table 6.6 Conventional farmer data estimation results

Variables	Full model	Short-run effect of subsidies	Long-run effect of subsidies	Short-run effect of social learning	Long-run effect of social learning
Subsidies					
Cost	2.786***	9.400***	2.159***		
	(0.000)	(0.000)	(0.000)		
Income	4.054***	9.973***	3.810***		
	(0.000)	(0.000)	(0.000)		
Role model farmers					
Same endowment	2.862***			4.883***	2.116***
	(0.000)			(0.000)	(0.000)
Low endowment	1.515***			1.708***	0.988***
	(0.002)			(0.009)	(0.001)
High endowment	2.237***			2.508***	1.447***
	(0.000)			(0.000)	(0.000)
Orange ball	-0.173	-0.530	-0.248	0.213	-0.276
	(0.271)	(0.204)	(0.363)	(0.517)	(0.200)
Gender	-0.297	-0.589	0.092	-0.710	-0.255
	(0.392)	(0.297)	(0.764)	(0.167)	(0.210)
Age	-0.051***	-0.058**	-0.032**	-0.079***	-0.038***
	(0.002)	(0.046)	(0.019)	(0.008)	(0.000)
Size of land	0.012	0.005	0.001	-0.016	0.001
	(0.349)	(0.806)	(0.935)	(0.385)	(0.876)
Ln(income)	-0.142	-0.657**	-0.504***	0.227	0.032
	(0.236)	(0.023)	(0.002)	(0.319)	(0.678)
Khon Kaen	0.138	-2.695***	-0.723**	0.422	0.297
	(0.734)	(0.000)	(0.040)	(0.514)	(0.226)
Buriram	2.005***	1.014	0.390	4.904***	2.478***
	(0.000)	(0.120)	(0.276)	(0.000)	(0.000)
Constant	4.721***	10.306***	7.672***	-0.028	1.202
	(0.008)	(0.008)	(0.000)	(0.992)	(0.301)

Log likelihood	-634.938	-165.921	-181.164	-329.285	-303.959
Observation	4,400	600	1,400	960	2,240
Individual	440	200	200	320	320

Note: Numbers in parentheses are p-value. ***, **, and * are significant level at 1%, 5%, and 10%, respectively.

5. Conclusions

This chapter sheds light on the question of how to persuade farmers to adopt organic rice practice. Using a lab-in-the-field experiment, this study finds that temporary subsidies either cost subsidy or income subsidy would be able to increase adoption of organic rice prior to the point when they become privately profitable. When comparing the long-run effects of both subsidies, our results reveal that income subsidy would be more effective than cost subsidy. This is because the cost subsidy may create psychological effect after it is removed as farmers may treat instantly increasing in cost of organic rice that they need to pay by themselves as a loss. To avoid this loss, it would be possible that some would convert back to conventional rice because its production cost is less than that of organic practice. On the other hand, farmers with income subsidy may not feel removing income subsidy as a loss because the return from organic rice practice is significantly higher than that of conventional practice after the subsidy is ended.

In addition, even though we find that information provided by role model farmers is also important as it generally increases adoption of organic rice, the information provided by what types of role model farmers is much more important. This point is of interest. If we want to increase organic rice adoption through social learning, which may provide better cost-effectiveness than subsidy regime, then the main focus should be on what type of farmers would be early adopters or role models who could make their advice more credible to others. Our finding suggests that participant farmers seem to follow organic rice adoption advised by a role model farmer whose characteristics are the same or similar with them.

Our findings point to both subsidies and network-based communication campaigns that could be considered as intervention options for government and other actors that want to increase the adoption of organic rice. While our results are limited to the nature of lab-in-the-field experiment in which the consequences caused by decision made in the experiment do not reflect real life situation, they suggest that investing in real life pilot test of these interventions would be worthwhile.

Note that the interventions studied in this chapter are the interventions that aim to induce farmers to switch from conventional rice practice to organic rice practice. However, to make farmers continue practicing organic rice practice after adopting it data from our household survey suggests that other factors especially availability of certain organic rice market with premium price, low barrier of getting organic certificate, and extension supports to enhance organic rice yield need to be fulfilled.

A synthesis document outlining the key results and conclusions of the research has been published separately and is available on the teebweb.org website along with a summary of the key messages from the analysis.

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Appendix 1: Summary tables used to develop the methodology

Table A1.1 TEEB Agrifood Framework Systems Table with indicators and data sources

			Stock				Flows			Outcomes			
	Product	**Method Practices**	**Natural capital**	**Human capital**	**Produced capital**	**Social capital**	**Ecosystem service inputs**	**Purchased inputs**	**Residuals Outputs**	**Natural capital**	**Human capital**	**Produced capital**	**Social capital**
	Rice	Conventional practice	Existing land	Labor (farmers)	Loans	Farmer cooperation/ group	Biology pest control	Chemical fertilizer	Nutrient runoff to stream	Change (loss or improve) in soil health	Farmer's and consumer's health: Pesticide uses	Conventional practice: low profit because of higher costs of pesticides and chemical fertilizer	Conventional practice: Seasonal migration of farmers due to no agricultural activities during dry season
		Organic practice	Water (Rainfall) Plants in rice field and surrounding Habitat (connectivity) and biodiversity Soil structure (Soil health)	Consumers	Community rice mills	Social networks	Nutrient cycling Biomass accumulation	Organic fertilizer Labor Pesticides Energy Machinery rental cost	GHG emission from burning rice straw GHG emission from rice straw fermentation Air pollution (pm10) from burning rice straw Rice loss during harvesting and milling Amount of energy use for milling.	Change (loss or improve) of habitat and biodiversity quality Change (loss or improve) in ecosystem services and species	Farmer's and consumer's health: Air pollution Precise agricultural skill and management skill improvements Increase choice of rice variety for consumers Ecotourism	Organic practice: low profit during the early stage of adopting the organic practice but higher profit in the long run due to lower cost of production. Group or cooperation rice mills	Organic practice: Formal farmers' cooperation and groups. Improvement of farmers' social network and trust. Land displacement Increased opportunities of employment for women in rural areas.

	Product	Method Practices	Stock				Flows			Outcomes			
			Natural capital	**Human capital**	**Produced capital**	**Social capital**	**Ecosystem service inputs**	**Purchased inputs**	**Residuals Outputs**	**Natural capital**	**Human capital**	**Produced capital**	**Social capital**
Indicator	Area (ha) of rice	Area (ha) of conventional rice practice Area (ha) of organic practice	soil pH, soil texture, organic matter (OM), total nitrogen (TN), total phosphorus (TP), potassium (K) and total organic carbon (TOC), and soil erosion. For water, Total alkalinity as CaCO3, total phosphorus (TP), total nitrogen (TN), potassium (K), total organic carbon (TOC), dissolved organic carbon (DOC) and total dissolve nitrogen (TDN). Plankton, Microbial, Invertebrate, and Vertebrate biodiversity, Aerial insects, and vegetation biomass	Number of farmers in both practices (and their characteristics) Number of domestic consumers	The amount and institution that lent the money and their interest rate and conditions. Number of rice community mills.	Number of formal farmer's cooperation and groups as well as number of members.	Species richness and composition, soil and water characteristics	Tons of chemical fertilizer Tons of organic fertilizer Number of hired labor Amount of pesticide (Tons, Litters) Value of machinery	Amount of GHGs emission from rice cultivation, Amount soil carbon sequestration, Amount of air pollution (pm10) from burning rice straw, Amount of rice loss during harvesting and milling. Amount of energy use for milling. Response and local exploratory variable for model to predict crop production, distribution and abundance of species-habitat.	Amount of crop production per area due to association with species, environments.	Treatment cost or value of statistical life (VSL) due to changes in risk of exposure to pesticide. Treatment cost or VSL due to change in risk of exposure to PM2.5 and PM10. Well-being of consumer due to increase in choice of rice variety measured by WTP.	Amount of profit from growing rice. Number of community rice mill cooperation and groups.	Number of family members migrated to work outside community during dry season. Subjective well-being of farmers. Number of formal farmer's cooperation and groups as well as number of members. Number of women members in formal farmer's cooperation and groups.

	Product	Method Practices	Stock				Flows			Outcomes			
			Natural capital	**Human capital**	**Produced capital**	**Social capital**	**Ecosystem service inputs**	**Purchased inputs**	**Residuals Outputs**	**Natural capital**	**Human capital**	**Produced capital**	**Social capital**
Data source			Primary field data from study sites	Secondary data from Ministry of Agricultural and Cooperatives and primary data_household survey level	Secondary data from Ministry of Agricultural and Cooperatives and primary data_household survey level	Secondary data from Ministry of Agricultural and Cooperatives and primary data_household survey level	Primary field data (e.g. species richness, composition, soil-water) and secondary spatial data (e.g. hydrology, geography, land use, soil map)	Secondary data from Ministry of Agricultural and Cooperatives and primary data_household survey level for amount of fertilizer use. Primary data_household level survey for number of hired labor and amount of pesticide uses.	Primary data_household level survey and secondary data from IPCC for GHGs and soil carbon estimation. Secondary data from literature review for air pollution, and Primary data survey for rice loss during harvesting and milling. Primary data form mills in the study area and secondary data for regional level. Landscape scale input for model to predict crop production, distribution and abundance of species-habitat.	Environmental background related to crop production associated with species composition.	Secondary data_Ministry of public health for treatment cost. Primary data_choice experiment survey for VSL. Primary data_choice experiment survey for consumer's WTP.	Primary data_household level survey.	Primay data_household level survey

	Product	Method Practices	Stock				Flows			Outcomes			
			Natural capital	**Human capital**	**Produced capital**	**Social capital**	**Ecosystem service inputs**	**Purchased inputs**	**Residuals Outputs**	**Natural capital**	**Human capital**	**Produced capital**	**Social capital**
Methodology									Century model for soil carbon sequestration. Model to predict crop production, distribution and abundance of species-habitat.	InVest model or other predictive models	Choice experiment method for estimating VSL of farmers and consumers on health related to air pollution.		Subjective well-being model accounted for life satisfaction related to family and truth.
											Choice experiment method for estimating VSL of farmers on health related to pesticide.		
											Choice experiment method for estimating WTP of consumers.		

Table A1.2. TEEB Agrifood framework impact description

Impact Description				
Capital	**Environment**	**Economic**	**Health**	**Social**
Natural capital				
Change (loss or improve) in soil health	Change in stock of healthy soil	Increase or decrease in income due to yield changes and cost of production		
Change of (loss or improve) habitat quality	Threatened species (i.e. Sarus Crane)	Increase or decrease food harvested from rice field		Change of social well-being due to (in)availability of threatened species through ecotourism
Change (loss or improve) in biodiversity and ecosystem services	Change in ecosystem services such as biological pest control	Cost of production increase or decrease due to change of biological pest control	Increase risk of being sick due to pesticide uses	
Human capital				
Farmer's and consumer's health: Pesticide uses			Improve or worst health condition	
Farmer's and consumer's health: Air pollution	Soil degradation or soil health improvement		Improve or worst health condition	
Precise agricultural skill and land management skill improvements	Soil health improvement	Increase income due to yield improvement and from off-seasonal crops		
Increase choice of rice variety for consumers				Change of social well-being due to more choice of rice variety for consumption
Enjoyment of ecotourism		Income from ecotourism		
Produced capital				
Conventional practice: Using pesticides and chemical fertilizer		Decrease in income due to continuously increase of chemical fertilizer and pesticide costs		
Organic practice: Using organic fertilizer and no pesticide		Low income during the early stage of adopting the organic practice but higher income in the long run due to lower cost of production and yield		
Group or cooperation rice mills		Increase or decrease milling efficiency		Improve social network, social capital, and social group
Social capital				
Conventional practice: Seasonal migration of farmers due to no agricultural activities during dry season		More income from working outside agricultural sector	Mental health reduced due to family separation	Break down of community network
Organic practice: Less seasonal migration due to practicing agricultural activity year round		Income from agricultural activity during dry season.	Better mental health due to family living together	Stronger social network in community
Organic practice: Formal farmers' cooperation and groups.				Stronger social network in community

Appendix 2: Additional information on Landuse Change Modelling

1. Study Design and Available Data

The prediction of spatial landuse changes for agricultural landscape involves the driving force of various natural process and human activities on land (Singh et al. 2020). Trends of land use changes are observed regionally for agricultural landuse. The rice paddy fields expansion is the main focus to investigate the pattern of changes. The simulated changed areas perform based on the organic area scenarios described in the scenario development section. The scenarios focus on the changing area of rice cultivation land, specifically conventional practice to organic practice. Thus, the conversion area of conventional rice to organic rice cultivation by the MoAC is the key concept used for controlling land-use change scenarios. Therefore, the primary goals were to (1) examine the spatiotemporal changes in LULC between 2015 to 2019 and (2) anticipate land use maps for 2025, 2030, 2035 utilizing spatial Markov chain modeling.

The primary purpose of this study is to use the thematic maps of land use for spatial and temporal analysis to predict organic rice area expansion in scenarios. The available data for land use change analysis primarily uses the maps produced by the Land Development Department, MoAC Thailand. Generally, the land use (LU) classification maps are produced every two years due to the limitation workforce. For a thematic map of NE region, the original LU at level 2 classified 31 classes of LU is grouped into ten major LU classes for 2015 and 2019. The reclassified LU are carried out to assess the accuracy of land use predictoins by using LU 2017 and organic paddy fields as reference points. The overall accuracy, user's accuracy, producer's accuracy, and kappa statistics were used to measure the accuracy. Using kappa statistics, the overall classification accuracy is computed by dividing the total number of properly categorized points by the total number of reference points (Lillesand and Kiefer 2008). (TableA1). The Kappa coefficients for the 2015 and 2019 categorized LULC maps are rounding 0.8 and 0.90, respectively. This demonstrates that the maps are accurate enough to be utilized for further investigation (Monserud, 1990).

Table A2.1. Accuracy assessment of classified LULC maps for 2015 and 2019

LU classes	2015		2019	
	Producer's(%)	User's(%)	Producer's(%)	User's(%)
Conventional rice	54.44	98.00	52.63	100.00
Organic rice	98.00	60.00	97.14	68.00
Field crop	73.08	76.00	91.11	82.00
Orchard	63.79	74.00	95.24	80.00
Rangeland	80.56	58.00	93.33	84.00
Forest	94.00	94.00	96.15	97.00
Urban	87.50	84.00	97.78	88.00
Wetland	97.56	80.00	100.00	94.00
Water	89.29	97.00	95.45	84.00
Others	82.05	64.00	90.00	90.00
Overall accuracy (%)	78.8		87.0	
Kappa coefficient	76.4		85.6	

1.2 Methods and rationales of LU Change Analysis

The scientific community of LULC change modeling is interested to quantitative assess of different LU categories, net change of each LU class, and contributions to the net change experienced by each LU category. Because it encompasses both environmental and socioeconomic aspects, predicting future LULC dynamics is a difficult task. The future LU simulation can be use to assess temporal and spatial changes in a specific area. The simulation of future LU and analysing the difference between historical and future land use. Many modeling tools are previously in use, including the Markov Chain model and artificial neural network (ANN) model. The Markov Chain model is successfully used to examine the simulation of land use change among several categories. Numerous studies agreed on the predictive efficiency of Markov Chain modeling in predicting changes in land usage from one period to the next and is used to forecast future changes (Kumar et al. 2014; Noszczyk, 2019; Roy et al., 2015). ANN is a non-parametric technique that can quantify and describe complicated non-linear patterns and is inspired by the human biological nervous system. It is capable to generate numerous parameter values using a limited amount of data and this save model in predicting growth of land use such as urban growth (Maithani 2015; Alqadhi et al. 2021). The Feed forward Neural Network (FNN) is a basic and widely used approach among the numerous forms of neural networks. There are two types of FNN methods: Single Layer Perceptron (SLP) and Multi-Layer Perceptron (MLP). MLP contains more than one perceptron layer and can solve more difficult and non-linear problems than SLP (Vicker 2017). To date, the MLP approach has been used to forecast the success of a number of different types of land use prediction. Additionally, predicting future LULC dynamics with the MLP neural network and Markov chain model performs a robustness and accuracy in the several studies. For example, the LU change prediction of urban LU simulation (Ozturk, 2015; Mishra and Rai, 2016), land-specific carbon emission pattern (Fattah et al.2021), agricultural fragmentation (Gomes et al. 2019), and predicting the expansion of planted forests in the future (Nery et al. 2019). The integrated MLP-Markov chain (MLP-MC) model is an effective method for modeling and quantifying spatiotemporal changes. The MLP-MC hybrid strategy combines the benefits of both models.

This study aims to analyze the LU change based on the historical changes of rice cultivation area in NE of Thailand. Such complex spatial variations in LU change situation is simulated regarding the organic rice expansion to predict the future LU in NE region. The rationale for such forecasts may be traced to the neural net's working principle, which utilizes non-linear functions and assumes that variables interact. The neural net also trains the model with the notion that a single land-use change driving variable might have many effects across the study region. Although the hybrid models can provides better understanding about LU change, it is difficult to determine the best result due to each study offers a distinctive conclusion. According to Arsanjani et al. (2011), the efficacy of LULC change models varies per research area due to differences in environmental conditions and study area characteristics. Thus, holding this assumption this study investigates the subject matter for a period of about 16 years (2020-2035), applying the MLP-MC model.

The LU change modelling and future scenarios simulation are performed using the land change modeller in Terrset software and GIS application in Quantum GIS. This modeler tool assesses and predicts LU change and its tasks including three major tasks for this study: 1) change analysis between an earlier LU date (T1) and later land use date (T2), 2) transition potentials (modelling the potential for land transitions), and 3) land change prediction (forecasting the direction of change in the future). We utilized this technique to examine land use changes in NE Thailand from 2015 to 2019, construct transition potentials of land use types trained using 2015–2019 data, evaluate the obtained potentials, and then forecast scenarios of future landuse change for 2025 to 2035.

1) Change analysis

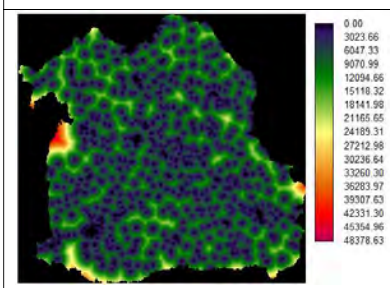
The land change modeler (LCM) for ecological sustainability, which is an integrated software package in Terrset, was used to conduct the LU change analysis, simulation, and future LU change prediction. The LCM is a set of tools for analyzing and modeling LU evolution. It allows users to map changes, identify transitions across LU classes, model, and anticipate future landscape situations by including user-specified change factors (Eastman 2018). In LCM, the change model is based on a Markov chain matrix produced by comparing LU maps from two dates (T1 and T2). The Markov chain projection is carried out by constructing a matrix that estimates the area of each LU class for future dates as well as the amount of change for each transition. Calculating the likelihood of each transition is used to measure the change potential (Eastman 2018). The transition from one class to another is recognized using LU change analysis. Cross tabulation analysis was used in this work to quantify LU variations from 2015 and 2019. This study can reveal the areas that shifted from one LU class to another within a specific time period both geographically and statistically (Mozumder and Tripathi 2014). In graphical form, the gains and losses by LU classes, contributions to net change in organic rice area, and examination of the geographical pattern of change for organic rice cultivation for periods 1 and 2 were also analyzed.

2) Transition potential modelling and model development

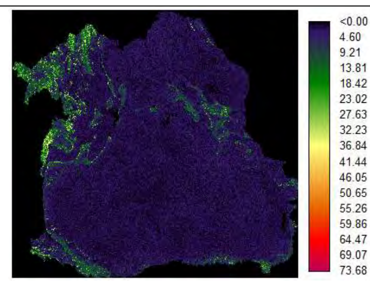
2.1) Selection of driver variables

Researchers have recorded many elements that may vary in their relevance from incident to incident as driving forces for land use change. There is no generally acceptable recommendation of driving forces for land use and land cover changes, and each research region must be assessed separately. The land use change modeling in this study aims, in particular, to investigate the agricultural pattern, conventional to organic rice area, changes over time. The major driving factors for land use change are complex because of various agricultural land use activities. The biophysical drivers, including slope and elevation, are significant characteristics of agricultural land use change (Motte et al., 2006). At the parcel level, the flatter and lower elevation parcel tend to change from croplands to meadows and the parcels with steeper slope and higher elevation cropland tend to be use for livestock farms or to be abandoned parcels (Van et al., 2015). Other major drivers of land use change are the socioeconomic factors including population growth, urbanization, and industrialization (Long et al., 2007). The fragmentation of agricultural land of paddy fields convert to urban development and construction because the need for rural dwelling land grew increases as the population grow. Considering the climate variables and land use prediction, the influence of future climate has been recognized as major factor altering soil erosion and basin hydrology resulting changes of land use (Anache et al., 2018). The climate variables includes in this study used in scenarios where response to climatic factors. For assessment of land use prediction, this study applies the future climate data of emission scenarios (Representative Concentration Pathways, RCP6.5) to provide forecasts for the effects of climate change on land use across the NE region using the EC-Earth model.

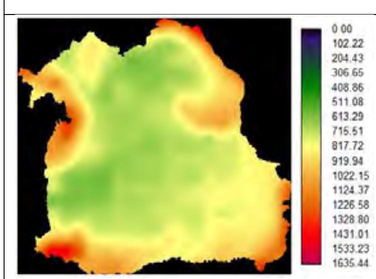
a. Urban distance



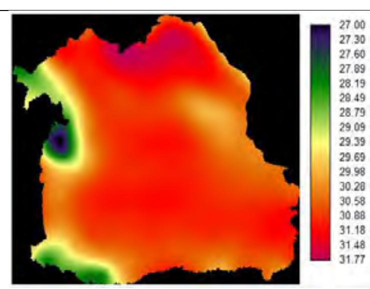
b. Slope



c. Mean precipitation(RCP4.5)



d. Max temperature (RCP4.5)



e. Min temperature (RCP4.5)

f. Mean temperature (RCP4.5)

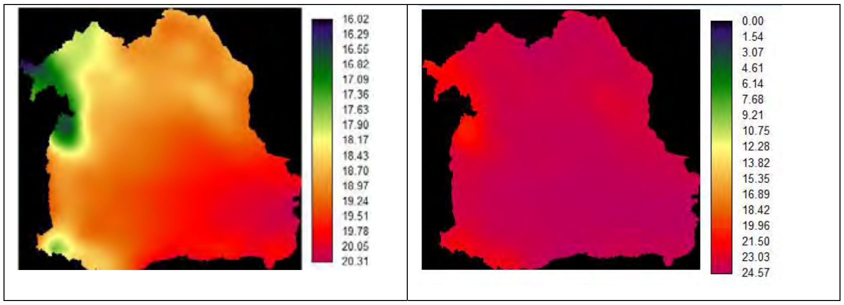


Figure A2.1. Explanatory variables used in this study

To quantify the association between each class of landuse and driving factors, Cramer's V statistic was utilized to identify the important driving forces for use in the modeling. The most related factors in two LU maps are determined using Cramer's V. It is useful if Cramer's V values is 0.15 or higher, and if Cramer's V is more than 0.4, the element association is beneficial (Eastman, 2012). It is used to determine the strength of a variable's relationship. Cramer's test (V) is calculated using the formula below for calculation.

$$V = \sqrt{\frac{\chi^2}{n(q-1)}} \quad (1A)$$

$$\chi^2 = \frac{(0-E)^2}{2} \quad (2A)$$

where c^2 is Chi-square coefficient, *n* denotes sample size, *q* denotes the smallest value in the rows and columns of the land use, *O* denotes observed frequency for a category, and *E* denotes expected frequency in the corresponding category.

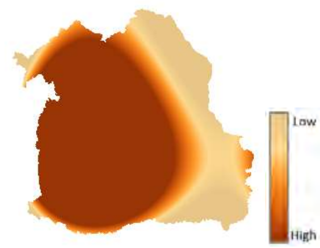
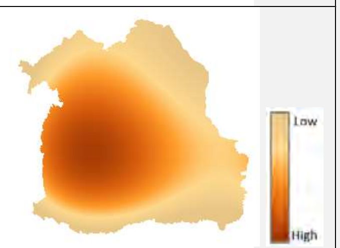
Table A2.2.

Variables	*Cramers' V*
Precipitation_mean	0.2370
Max temperature	0.3005
Mean temperature	0.3763
Min temperature	0.3466
Slope	0.2819
Urban distance	0.1895
Distant road network	0.0063
Organic 2017	0.0245
Convent to organic	0.1549
Trend of all to organic	0.1403

2.2) Selection of LU transitions

All transitions were evaluated in this study and selected only as significant potential causes causing LU change in the region. The inclusion of just key transitions has a significant impact on the research area's dynamics. To improve the performance of the MLP neural network, the significant transitions were added into the transition sub-model (Eastman 2006). The maps were generated from our analyses showing the generalized trends of classes with the most changes from 2015 to 2019. The likelihood of changing from conventional rice to organic rice lands (Figure a.) is higher almost the entire the NE. The field crop including cassavas, corn, sugar cane, is the second largest land located near the central NE and more likely to contribute to organic rice (Figure b). The rangeland in the northeast of the country is mostly covered by farmland where the chance for converting to organic rice is considerable (Figure c.). Similarly, the orchard land presents in Figure f. Although there is concerns in particular of wetland and forest land conversion to organic rice, the change trends of these two classes are quite relatively lower than other classes. Additionally, we have also created a map of areas that have not changed from 2015 to 2019 (Figure d, e, g). The majority of the regions' land has remained unchanged in terms of land use and land cover during this five-year period. Change has occurred in a few very small locations spread around the region and difficult to identify. Moreover, the persistent area in each LU class presents in Figure 2A.

Finally, we carried the major transitions to include the conventional rice to organic rice land, to predict the future LU maps.

a. Conventional to organic rice	b. Field crop to organic rice	c. Rangland to organic rice
		
d. Wetland to organic rice	e. Forest to organic rice	f. Orchard to organic rice

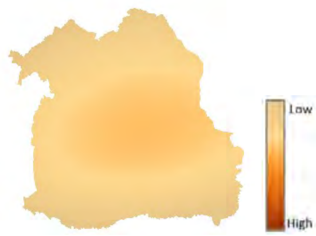
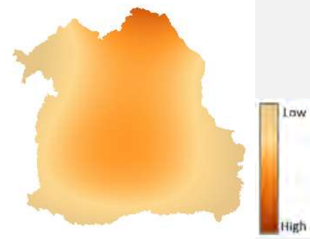
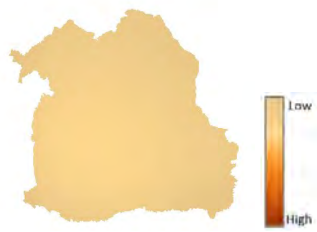
		
g. Water to organic rice		
		

Figure A2.2. Maps of spatial trend of changes. Note that the legend present in maps using the same values.

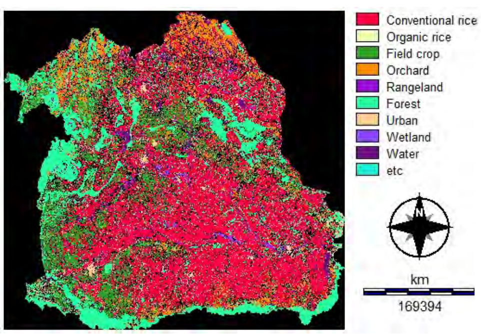


Figure A2.3. Map of areas that did not change between 2015 and 2019.

Transition potentials were modeled using a back propagation (BP) learning approach, which can model highly non-linear functions, and a multi-layer perceptron (MLP) neural network technique. We divided the land use transitions into "sub-models" based on their underlying driving factors once the two model variables (land use transitions and driving factors) were defined (Eastman, 2012). Each sub-model examines how the various factors explain a unique land-use shift that took place between 2015 and 2019. Relevant transitions are identified and simulated independently as sub-models based on change analysis. The factors that drive the transition from one class to another may be similar to those that influence the transition; for example, conventional rice land to urban land and from forest to urban land.

In MLP algorithm in LCM modeler, the training procedure employed samples collected from pixels that traveled through the transition being modeled, or pixels from persistence classes, to execute transition sub-models. The transition potential model was trained using 50% of the samples and validated with the remaining 50% of the samples. MLP in LCM offers with an automated training mode that can monitor and adjust the start and end learning rates based on the sample training data (Eastman, 2012). Except for the number of hidden layer nodes, all parameters have default values. When the sub-model was first run, the default hidden layer nodes were utilized. Following that, more running tests were carried out. The value will be doubled if the overall accuracy and skill score improve, else the last value will be used. Running MLP gave the report the overall accuracy as well as the skill measure score. When the MLP accuracy is more than 80%, the MLP learning algorithm successfully replicates the transition potential. Model skill is measured using the formula below (Eastman, 2012).

We used the MLP NN in LCM to develop the transition potential. The samples were taken from two LU maps (2015 and 2019). The minimum number of cells that transitioned from 2015 to 2019 was 1197336 for MLP to operate with 10,000 iterations. During the process, half of the cells were utilized for training and other half were used for validation. Eastman (2012) recommended that the accuracy rate around 80 % is acceptable. After running, MLPNN was completed with an accuracy rate of 83 percent, which is a quantification of calibration. This function was used to construct the transition potential maps. As a result, the created transition potential maps were utilized to forecast LU changes in the future. The skill measures and accuracy value reach the recommendation suggested by the software developer. Table 3A shows that we attained an accuracy rate of 83 percent with all variables. A skill value is higher than the software developer's recommended figures (Eastman, 2012). The skill measure is the difference between the measured and the predicted accuracy. The accuracy and skill values indicate that the variable 1, organic rice trend which is a trend conventional rice to organic rice, has the greatest impact on model performance. However, if the model skill of holding a variable constant is equivalent to the skill of modeling with all variables, the variable has no substantial effect on the model and may be deleted. This was not the case in our situation.

Table A2.3. Transition sub-model results: sensitivity of the model to forcing independent variables to be constant.

Model	Accuracy(%)	Skill measure	Influence order
With all variables	83.32	0.776	NA
Var.1 constant (organic rice trend)	33.49	0.0023	1st (most influential)
Var.2 constant (slope)	77.07	0.6560	5st (least influential)
Var.3 constant (urban distance)	76.88	0.6532	4
Var.4 constant (mean precipitation)	75.67	0.6351	3
Var.5 constant (mean temperature)	70.55	0.5582	2

3) Land change prediction and validation

The MLP approach was used for LU change prediction to specified future date for allocation of organic rice area change in LCM models. Based on the previous step, the transition probability matrix is used by the Markov model to account for variations in each class using the LU maps (2015 and 2019). The MC generates LU change predictions of the considered date based on the present state of the transition potentials for each transition, showing the maximum transition probability aggregation for all transition potentials (soft output). After that, a multi-objective land allocation method was used to assess all transitions and develop a list of classes that included both gain and loss land. During the execution of this allocation technique, all of the altered land of a class was assigned and overlaid to produce the outcome (Eastman, 2012). The model validation performs by calculating the association of the locations of organic rice paddy fields from household survey to train and present it as the external validation. Finally, MLP-MC was used to run the projections for 2025, 2030 and 2035, and potential changes in LULC were established.

The transition probability matrix is used by the Markov model to account for variations in each theme class across the time period under consideration. The probabilities matrix representing the likelihood of each LULC type changing to another type is listed in this table.

Table A2.4. Markov transition probability matrix of changing LU for 2025 under Scenario1

LU classes	Conventional	Organic	Field crop	Orchard	Rangeland	Forest	Urban	Wetland	Water	Others
Conventional	0.5168	0.0329	0.2634	0.0784	0.0201	0.0091	0.0423	0.0116	0.0252	0.0002
Organic	0.7280	0.0552	0.1414	0.0269	0.0103	0.0024	0.0180	0.0066	0.0111	0.0000
Field crop	0.0751	0.0053	0.6817	0.1604	0.0252	0.0173	0.0256	0.0016	0.0068	0.0009
Orchard	0.0427	0.0024	0.1763	0.7054	0.0189	0.0237	0.0199	0.0050	0.0056	0.0002
Rangeland	0.1294	0.0070	0.2177	0.1009	0.3704	0.0526	0.0638	0.0307	0.0273	0.0002
Forest	0.0337	0.0017	0.1138	0.0530	0.0176	0.7522	0.0192	0.0037	0.0052	0.0000
Urban	0.0212	0.0014	0.0289	0.0199	0.0179	0.0214	0.8809	0.0017	0.0068	0.0000
Wetland	0.2468	0.0105	0.0560	0.0454	0.0220	0.0074	0.0280	0.5073	0.0764	0.0000
Water	0.0297	0.0018	0.0125	0.0073	0.0057	0.0024	0.0098	0.0164	0.9141	0.0002
Others	0.2086	0.0097	0.2587	0.3331	0.0408	0.0108	0.0257	0.0087	0.0038	0.1001

Table A2.5. Markov transition probability matrix of changing LU for 2030 under Scenario1

LU classes	Conventional	Organic	Field crop	Orchard	Rangeland	Forest	Urban	Wetland	Water	Others
Conventional	0.2961	0.0232	0.3581	0.1454	0.0288	0.0202	0.0717	0.0148	0.0414	0.0004
Organic	0.1111	0.0000	0.1111	0.1111	0.1111	0.1111	0.1111	0.1111	0.1111	0.1111
Field crop	0.0956	0.0068	0.5458	0.2263	0.0316	0.0296	0.0457	0.0042	0.0136	0.0008
Orchard	0.0650	0.0041	0.2526	0.5594	0.0257	0.0373	0.0369	0.0073	0.0115	0.0003
Rangeland	0.1416	0.0089	0.2840	0.1524	0.1825	0.0667	0.0914	0.0307	0.0415	0.0003
Forest	0.0527	0.0031	0.1761	0.0937	0.0238	0.5988	0.0353	0.0058	0.0105	0.0001
Urban	0.0331	0.0022	0.0563	0.0380	0.0237	0.0350	0.7957	0.0033	0.0127	0.0000
Wetland	0.2618	0.0144	0.1362	0.0824	0.0274	0.0145	0.0510	0.2996	0.1126	0.0001
Water	0.0453	0.0029	0.0292	0.0163	0.0086	0.0050	0.0188	0.0233	0.8503	0.0003
Others	0.1767	0.0111	0.3216	0.3366	0.0383	0.0240	0.0470	0.0110	0.0132	0.0205

Table A2.6. Markov transition probability matrix of changing LU for 2035 under Scenario1

LU classes	Conventional	Organic	Field crop	Orchard	Rangeland	Forest	Urban	Wetland	Water	Others
Conventional	0.2550	0.0165	0.3522	0.1738	0.0295	0.0273	0.0838	0.0140	0.0474	0.0004
Organic	0.3285	0.0212	0.3365	0.1423	0.0273	0.0203	0.0697	0.0138	0.0401	0.0004
Field crop	0.1134	0.0074	0.4654	0.2534	0.0328	0.0384	0.0620	0.0063	0.0202	0.0007
Orchard	0.0851	0.0053	0.2923	0.4631	0.0287	0.0466	0.0525	0.0086	0.0175	0.0004
Rangeland	0.1480	0.0091	0.3067	0.1831	0.0982	0.0705	0.1074	0.0259	0.0506	0.0004
Forest	0.0705	0.0042	0.2179	0.1272	0.0269	0.4798	0.0501	0.0072	0.0160	0.0002
Urban	0.0456	0.0029	0.0816	0.0552	0.0261	0.0447	0.7210	0.0045	0.0183	0.0001
Wetland	0.2497	0.0142	0.1949	0.1131	0.0285	0.0211	0.0688	0.1794	0.1300	0.0002
Water	0.0596	0.0036	0.0467	0.0264	0.0106	0.0075	0.0273	0.0260	0.7921	0.0003
Others	0.1595	0.0100	0.3410	0.3180	0.0351	0.0344	0.0644	0.0115	0.0215	0.0044

Appendix 3: Rice yield production function

The results of the mean test (using *t-test*) presented in Table 4.38 indicates that rice yield from conventional and organic practices is not different. However, this test directly compares the mean of rice yield without taking into account other variables such as amount of fertilizers that may alter yields. To make sure these two practices exactly yield difference or not when considers to other factors together, we estimate the rice yield of conventional and organic practices by a Cobb Douglas function where other relevant variables are included for analysis. The initial production function in each practice consists of inputs such as labor, machinery, fertilizers, pesticides, seeds, and type of cultivation practices. The production function can be expressed by the equation below:

$$Yield_i = \beta_0 + \beta_1 Seed_i + \beta_2 Nitrogen +_i \beta_3 Phosphorus_i + \beta_4 Potassium_i + \beta_5 Pest_i + \beta_6 Labor_i + \beta_7 Capital + \beta_8 Buriram_i + \beta_9 Surin_i + \beta_{10} N_{-Org_i} + \beta_{11} P_{-Org_i} + \beta_{12} K_{-Org_i} + \beta_{13} L\_org_i + \beta_{14} C\_org_{\ i} + \beta_{15} Org_i + \varepsilon_i$$

where i indicates plot i.

$Yield_i$ is the rice production (kg/rai).
$Seed_i$ is the quantity of seed (kg/rai).
Nitrogen (N) is the quantity of Nitrogen (kg/rai).
Phosphorus (P) is the quantity of Phosphorus (kg/rai).
Potassium (K)is the quantity of Potassium (kg/rai).
Pest is the value of chemical pesticide (baht/rai).
Labor is value of labor used in rice cultivation (baht/ rai).
Capital is the rental value of machines used in rice cultivation (baht/ rai).
$Buriram_i$ is a dummy variable that is equal to 1 if plot i at Buriram province and 0 otherwise.
$Surin_i$ is a dummy variable that is equal to 1 if plot i at Surin province and 0 otherwise.

N_org_i is interaction variables to identify whether nitrogen affect yield organic rice differently from convention rice.

P_org_i is interaction variables to identify whether phosphorus affect yield of organic rice differently from convention rice.

K_org_i is interaction variables to identify whether potassium affect yield of organic rice differently from convention rice.

$\mathrm{C\_org}_i$ are interaction variables to identify whether capital affects yield of organic rice differently from convention rice.

$\mathrm{L\_org}_i$ are interaction variables to whether labor affects yield of organic rice differently from convention rice.

Org is a dummy variable that is equal to 1 if plot i performs organic practice and 0 otherwise.

Table A3.1 presents the two different models of the Cobb Douglas function. The first model was estimated using ordinary least square (OLS) method, meanwhile the second one was employed maximum likelihood (ML) method. The two models reported in Table A3.1 reveal very similar results when considering the difference between two practices. Both models indicate that conventional rice practice and organic rice practice yield the same amount of rice per hectare after controlling for all relevant variables, about 321 kg per rai, due to the fact that Org variable is not statistically significant. It should be note that this result just points out only the cross-section data. The impact of climate change and other environmental change were not captured as the previous yield prediction model. Seed, value of chemical pesticide, value of labor, and the rental value of machines are not statistically significant to impact the rice yield based on the amount of these inputs applied in our samples. However, the result showed that capital use in organic practice increase rice yield with the statistically significant levels at 5%. Based on our descriptive data, the organic practice normally uses plantation machine that increase the capital cost. In the meanwhile, the yield from plantation machine practice could be higher than that from paddy-sown field that normally applies in conventional rice practice (Kongtanajaruanun and Cheamuangphan, 2018). The quantity of Phosphorus and Potassium use are not statistically significant impact on rice yield. The one kilogram of nitrogen, however, increase rice yield about 4.737 kg per rai with the statistically significant levels at 5%. The quantity of nitrogen indifferently impacts yields of both conventional and organic rice practice. The different climate, soil texture, and other factors related to geographical location in our study area is captured by province dummy variables where Khonkaen is used as reference. The results show that the rice yields in Khonkaen and Surin are indifferent, but rice yield in Buriram is significantly higher than those provinces by about 24.87 kg per rai.

Table A3.1: Results of the Cobb-Douglas production function estimations of rice yield

Variables	Model 1	Model 2
Seed	- 0.451	- 0.451
	(0.301)	(0.300)
Nitrogen (N)	4.737**	4.737**
	(1.871)	(1.862)
Phosphorus (P)	- 3.002	- 3.002
	(2.767)	(2.754)
Potassium (K)	- 2.988	- 2.988
	(2.633)	(2.621)
Pest	0.031	0.031
	(0.187)	(0.186)
Labor	0.052	0.052
	(0.034)	(0.034)
Capital	- 0.006	- 0.006
	(0.026)	(0.026)
Buriram	24.867*	24.867*
	(14.226)	(14.157)
Surin	- 1.963	- 1.963
	(11.689)	(11.633)
N_org	- 0.155	- 0.155
	(6.382)	(6.382)
P_org	- 9.248	- 9.248
	(8.126)	(8.126)
K_org	.030	.030
	(6.212)	(6.183)
L_org	- 0.053	- 0.053
	(0.048)	(0.047)
C_org	0.086**	0.086**
	(0.041)	(0.041)

Variables	Model 1	Model 2
Org	- 27.461	- 27.461
	(27.662)	(27.530)
Constant	321.405**	321.464**
	(23.262)	(125.200)
Number of Observations	1,679	1,679
R-squared	0.017	-
Log likelihood	-	-10,922.094

Note: Standard error are in parentheses. *, ** and *** indicate significant levels at 10%, 5% and 1%, respectively.

APPENDIX 3 - Rice yield production function

Appendix 4: Choice experiment

To determine variables that would affect farmers' decisions on whether or not to adopt organic rice practice, we introduce hypothetical situation of organic rice practice compared to conventional practice. The hypothetical situation of organic rice practice consists of five attributes, which are the presence of natural enemies of pest, air quality presented by level of PM2.5, the risk of dying from pesticide poisoning, the number of years in which yields fell by 50 percent within the previous decade, and the price of rice. Table A4.1 provides an overview of the attributes used and their levels distinguished within each attribute.

1. The presence of beneficial insects attribute consists of two attribute levels, which are the presence or absence of beneficial insects. This attribute provides information to the farmers that the availability of beneficial insects could control pests in their rice field resulting in no cost of pesticide and low yield damage.
2. The PM2.5 level attribute represents the difference in post harvest activity between organic rice practice and conventional practice. One of the main causes of PM2.5 contamination in the air is from burning rice straw after harvesting. However, for organic rice farming, burning after harvesting is prohibited. This would correspond to a reduction in the PM2.5 level. From the World Air Quality Index project (2020), the peak concentration levels of PM2.5 from rice straw burning usually occurs from January to May. During that period, the PM2.5 level exceeds the standard level for about 90 days. We use this number as the reference and then design two fictive reductions of the number of days in which the PM2.5 level exceeded the standard level.
3. The next attribute is incidence rate of dying from pesticide poisoning applied in the rice field. Real estimates of risks of dying from pesticide poisoning applied in the rice field are not available for Thailand. We therefore gathered current incidence rates reported by National Health Security Office (2019) and calculate average incidence rate resulting in 5 out of 10,000 farmers died from pesticide poisoning. This number is used as reference. And, since the chemical pesticides are not used for organic rice practice, two fictive reductions of incidence rate are added as attribute level.
4. For the attribute of number of years within the decade of losing yield by 50 percent, this attribute presents risk of organic rice practice. There is a very high chance that yield of rice is significantly lower in at least the first three year after switching from

conventional practice to organic practice. We want to test whether this factor would be a significant barrier preventing farmers to switch to organic practice.

5. The final attribute is the price of rice. This attribute is designed to capture what would be the price at which farmers would accept to switch from conventional rice practice to organic rice practice. The attribute level covers the price range of conventional and organic Jasmine paddy rice price in the past seven years, 2011-2017.

Table A4.1 Attributes and levels

Attribute	Attribute level
Availability of beneficial insects	Yes
	No
Incidence rate of farmers dying from pesticide poisoning	1/10,000
	3/10,000
	5/10,000.
Number of days in which PM2.5 exceeded standard levels	70
	80
	90
Price of rice received by farmer (Baht per Kilogram)	12
	15
	17
	18
	20
Number of years within the decade of losing yield by 50 percent	1
	3
	5

The five attributes with their levels create $3^3*2*5 = 270$ possible combinations. We reduced these possible combinations to 36[71]. Next, we randomly paired them to form a choice set with each

[71] This is called fractional factorial designs. The design is able to estimate the main effects, but not the interaction effects. The design has properties of orthogonality and balance, whereby each attribute's level occurs in the same or

choice set contains two different combinations and the third choice contains the information of each attribute under conventional rice practice. Note that the third choice is fixed in every choice set. This resulted in 18 different choice sets in total. We then randomly divided them to three groups with each group having six choice sets. Thus, we ended up with three different sets of questionnaires that contained different choice sets, which are randomly distributed to respondents. Table A4.2 presents the example of choice set asked in the questionnaire.

Table A4.2 Example of choice set

Attribute	Organic rice A	Organic rice B	Conventional rice
Availability of beneficial insects	Yes	No	No
Incidence rate of farmers dying from pesticide poisoning	1/10,000	5/10,000	5/10,000
Number of days PM2.5 exceeded standard level	80 days	70 days	90 days
Price of rice (per Kilogram)	15 baht	20 baht	12 baht
Number of years within the decade of losing yield by 50 percent	5 years	3 years	1 year
I prefer to choose…….	☐	☐	☐

Survey implementation

The data for this study are collected from face-to-face interview in three provinces of Northeast regions of Thailand during December 2020 to March 2021[72]. These provinces include Buriram, Khon Kaen, and Surin. The sample set for this study consists of heads of organic and conventional rice farming households in these provinces. We first selected villages which hosted both conventional and organic farmers within the same area. We then requested village heads to find both types of farmers who agree to participate in the survey. The survey is carried out at a place within the community such as at a temple, school or the house of the head of the community. To

similar frequency as other levels (Zwerina, 1997). We used the macro module developed for choice experiment, experimental design, and conjoint choice analysis in SAS software to arrange this design (Kuhfeld, 2005).

[72] Due to second wave of Covid19, the survey was stopped during the first week of January 2021. More data will be collected in the next field survey, which will be started in the second week of March.

compensate for their time, each participant received 100 Baht (about \$3) after finishing all parts of the survey. During the interviews, 10 to 12 participants are gathered in each group session, after signing the consent form, each respondent participated in one-on-one interviews. Participants are given information sheets containing detailed information about each attribute. Note that since each information sheet provided to the respondents contained details of one attribute, the respondent might give the most attention to the first issue and less or none to the last one. This would cause bias on their choice selection, in which they may tend to select choices that favor the issue they read first and ignore the rest. To avoid this problem, the information sheets were given to the respondents in random order.

After participants read information sheets, enumerators verbally explain the details of each attribute again. After farmers confirm that they understand the situation, they were then asked to answer six choice set questions. After completing the choice experiment questions, respondents were then asked to finish the rest of the questionnaire. Following these steps of implementation, 502 farmers participated in the survey, 251 conventional farmers and 251 organic farmers.

Econometric Model and Monetary Valuation

In preference approach, it is assumed that an individual wishes to maximize utility subject to income. In this regard, utility for the farmer can be expressed by the following equation representing the utility function (1)

$$\mathrm{U}(\mathrm{X}_0, \mathrm{y}) = \mathrm{U}(\mathrm{X}_1, \mathrm{y} + \mathrm{WTA})$$

where **X** represents the vector of factors related to farming condition, and $\mathbf{X_1} \geq \mathbf{X_0}$. Improvement in **X** increases utility of farmers (i.e. $\partial U / \partial \mathbf{X} > 0$). An individual's stated preference willingness to accept (WTA) is the minimum additional amount of income that the farmers would require for changing from current conditions to new conditions.

We applied the conditional logit model to analyze the choice between alternative situations. Our conditional logit model is based on a random utility model (RUM) in which the farmers will choose the condition that provides them with the highest utility. However, we cannot know their utility. We can only observe indirect utility function denoted as V, and the unobservable part or stochastic component of the utility that is unknown denoted as ε. Therefore, the utility can be represented as following

$$U_{ij} = V_{ij} + \varepsilon_i$$

where U is the utility function. The indirect utility function would be observed by choice experiment questions in which the attributes are arguments. Hence, V can be expressed as a function of attributes accompanying each alternative

$$V_{ij} = \alpha_i + \boldsymbol{\beta}\mathbf{X}_i, \qquad \forall_i \in C$$

where $\mathbf{X}$ is the vectors of k attributes, $\boldsymbol{\beta}$ is a coefficient vectors, α is alternative specific constant (ASC), and i is an alternative in choice sets C. The probability that choice i will be selected by a farmer j is equal to the probability that the utility gained from selecting choice i is greater than that from any other choices. If we assume that the distribution of stochastic component is independently and identically distributed (IID) according to Gumbel random variable, then the probability of choosing choice i among those available (1, 2,…,k) $\in C$ can be expressed in closed form as

$$P_{ij} = \frac{exp\big(\mu(\alpha_i + \boldsymbol{\beta}\mathbf{X}_i)\big)}{\sum_{k\in C} exp\big(\mu(\alpha_k + \boldsymbol{\beta}\mathbf{X}_k)\big)}$$

where μ is a scale parameter, which is inversely related to the variance of the error term. The likelihood functions of conditional logit model with one data set can be represented as follows

$$L_r = \sum_{i=1}^{N} \sum_{P_i \in C} y_{in} \ln P_{in}\left(\mathbf{X}_{in} | \boldsymbol{\alpha} \;\; , \boldsymbol{\beta} \;\; \right)$$

where y_{in}= 1 if a respondent selects choice i, = 0 otherwise, n represents the index of respondents from choice experiment data, and $P_{in}\left(\mathbf{X}_{in} | \boldsymbol{\alpha} \;\; , \boldsymbol{\beta} \;\; \right)$ is the probability of a respondent choosing choice i. In such models the scale parameter, μ, is typically set equal to 1 because it is unidentifiable within any particular data set (Haener et al., 2001; Boxall et al., 2003; Lusk et al., 2003). However, in our case there are actually two data sets, which were collected from different groups of farmers, conventional and organic farmers. Therefore, the scale parameter could be identified. In addition, identification of the scale parameter is important in this study because we may not be certain to assume the equivalent preference among these groups of farmers. This due to the fact that, without accounting for the scale factor, if the estimated results represent preference's heterogeneity between groups, we cannot be certain whether differences in the parameter estimates are a result of differences in scale factor or differences in true underlying preferences. We therefore employ the combined data set estimation proposed by Louviere et al. (2000) to account for the relative scale factors, whereby the likelihood function of the combined data model is the sum of the conditional log likelihoods of conventional and organic farmers that is showed as following[73]

$$L_j = \sum_{r=1}^{2} \left(\sum_{n=1}^{N} \sum_{P_i \epsilon C_n} y_{in}^r \ln P_{in}^r (\mathbf{X}_{in}^r | \boldsymbol{\alpha}^r, \boldsymbol{\beta}^r, \mu^{or}) \right)$$

where r represents two groups of farmers. Full information maximum likelihood method is employed to simultaneously optimize this equation with respect to all parameters including relative scale parameters of organic farmers, μ^{or}.

In addition to the conditional logit model, we also estimated data from our choice experiment survey using the mixed logit model. This estimator relaxes the assumption of conditional logit model that the coefficients of attributes are the same across all individuals. In other words, the mixed logit model allows coefficients to vary within a given population. The probability of choosing choice i among those available (1, 2,…,k) ϵ C is similar to conditional logit model. However, instead of fixing coefficients across individuals, the mixed logit model allows them to vary. Hence, the probability of choosing choice i among those available (1, 2,…,k) ϵ C for individual j can be expressed in closed form as

[73] In order to find the relative scale parameters, we normalize the inclusive value of parameter associated with conventional farmers data to unity.

$$P_{ij} = \frac{exp\left(\left(\alpha_{ij} + \boldsymbol{\beta}_j \mathbf{X}_{ij}\right)\right)}{\sum_{k\epsilon C} exp\left(\left(\alpha_{ij} + \boldsymbol{\beta}_j \mathbf{X}_{kj}\right)\right)}$$

where $\boldsymbol{\beta}_j$ represents vector of coefficients that vary across individuals. Full information maximum likelihood is also employed to calculated $\boldsymbol{\beta}_j$.

In case of valuation estimation, following Hanemann (1999), welfare measures obtained from the conditional logit model and mixed logit model can be calculated as a marginal rate of substitute (MRS) between interested attribute and marginal utility of income presented as follows

$$MP_k = -\frac{\beta_k}{\beta_p}$$

where MP_k is the value of attribute *k.* The value of β_p is the marginal utility of income, represented by the coefficient of price, and β_k is coefficient of the attribute that we want to identify monetary value.

Results

Data was obtained from 502 individuals who participated in the choice experiment survey during December 2020 and March 2021. The proportion between organic farmers and conventional farmers who participated during this survey is 50:50 percent. Table A4.3 presents the results of the estimation.

Both the mixed logit model and combining model provide very similar results in terms of significance level and sign of coefficients. This suggests the quality of data obtained from the choice experiment survey was good, which may be related to efficient design and careful response to the questions by respondents. All attributes in both models were significant, suggesting that these attributes would alter farmers' decision on whether or not to adopt the organic rice farming. Starting with the presence of beneficial insects attribute, the coefficient of this attribute in both models is statistically significant with positive sign indicating that farmers prefer the availability of beneficial insects in their field. This result is in line with our expectations because the presence of beneficial insects could help farmers to control insects that could damage rice. In addition, it could also help farmers to reduce or stop using pesticide resulting in lower cost of production.

In case of incidence rate of farmers dying from pesticide poisoning, the coefficient of this attribute is significant with negative sign suggesting that the lower the incidence rate, the better. In particular, farmers do not like the high incidence rate of dying from pesticide poisoning. The lower incidence rate improves famers' utility as they would feel more secure facing a lower risk.

The coefficient of the number of days on which PM2.5 levels exceeded the standard caused by burning rice straw after harvest is negatively significant in both models. This result indicates that farmers are concerned about the level of PM2.5 because it could directly impact their health and others in their family. If the number of days PM2.5 exceeded standard level could be reduced through reducing areas of rice straw burning, then their utility would therefore increase and the chance of adopting organic practice will likely increase.

The next variable that is also statistically significant is the number of years losing yield by 50 percent. This variable represents the risk of early switching from conventional rice practice to organic rice practice whereby in the early stage of the transition period there is a high chance that the yield would fall sharply because soil fertility is still low and no chemical fertilizer can be applied. The result indicates that the higher the number of years of significant yield loss, the lower the farmers' utility and the lower the chance of organic rice practice adoption.

The last variable that is significant is the farmgate price of paddy rice. As expected, this variable is statistically significant with positive sign suggesting that the higher the price that farmers could get from organic rice, the more it would induce them to switch to organic rice practice.

From the results of choice experiment survey, it seems that the factors that directly impact farmers - risk of dying, risk of losing yield, and price of rice -, and the factors related to the environment - presence of beneficial insects and PM2.5 levels - would be important factors that would be able to incentivize farmers to switch to organic rice practice.

Table A4.3 Results of the estimation of the farmer's choice experiment

Variable	Mixed logit model	Combining model
Availability of beneficial insects	0.574**	0.089*
	(0.222)	(0.052)
Risk of dying from pesticide poisoning	-1.057***	-0.297***
	(0.342)	(0.018)
Number of days PM2.5 exceeds standard level	-0.064***	-0.022***
	(0.022)	(0.004)
Price of rice	0.409***	0.131***
	(0.134)	(0.011)
Number of years within the previous decade of losing yield by 50 percent	-0.784***	-0.251***
	(0.247)	(0.024)
ASC	-1.691**	-0.562***
	(0.714)	(0.113)
Scale value		0.831***
		(0.051)
Log-likelihood	-2,393.958	-2,426.488
Observations	9,035	9,035

Note: Standard errors are in parentheses.

***, **, and * represent significance levels at 1%, 5%, and 10%, respectively.

Next, we use the results of the estimation presented in Table A4.3 to calculate the monetary value of availability of beneficial insects, the changes in incidence rate of dying from pesticide poisoning, the number of days PM2.5 exceeded standard level, and the number of years losing yield by 50 percent. The monetary values are estimated using Krinsky Robb (parametric bootstrap) method (Hole, 2007), which provides 95% confidence interval of the values. Table A4.4 reveals the results. The second and third columns present the marginal monetary values calculated based on results from mixed logit model and combining models, respectively.

The marginal monetary value of availability of beneficial insects ranges between -1.40 to -0.68 suggesting that farmers would willing to accept a reduction of the price of rice by about 1.40 Baht to 0.68 Baht per kilogram if there are beneficial insects in their rice field. This number could be converted to an average total monetary value of beneficial insects in the rice field placed by farmers by multiplying the marginal value (-1.40 to -0.68 Baht per Kilogram) by the average amount of rice produced by each household. From our socio-economic survey, each household on average produces a total of about 6,220.12 kilograms of rice each year. Therefore, the total value of beneficial insects in the rice field is about 4,230-8,708 Baht per household.

For the risk of dying from pesticide poisoning, the marginal monetary value is between 2.278-2.582 Baht, which means farmers would accept at least an increase in the farmgate price of rice by 2.278-2.582 Baht per Kilogram for an increase in risk of dying from pesticide poisoning by 0.0001 percent (1 out of 10,000). We can convert this number to an average total monetary value that a household puts on avoiding the risk of hypothetical death from pesticide poisoning by multiplying the marginal value by the average amount of rice produced by each household, 6,220.12 Kilogram each year. This means the average monetary value of the change in risk of dying from pesticide poisoning by 0.0001 percent ranges between 14,169.43- 16,060.35 Baht per household.

The next factor that affects farmers' decision to switch to organic farming is the number of days on which PM2.5 levels exceeded standard level. The value of this variable is about 0.158 to 0.168 Baht meaning that farmers would require an increase (decrease) in the price of rice per kilogram by at least 0.158 to 0.168 Baht for one additional day with PM2.5 level passing standard level. We can again calculate the average value of air quality measured by PM2.5 levels by multiplying the average amount of rice produced by each household by the marginal value, which results in the average monetary gain from reducing one day on which PM2.5 exceeded standard level between 983-1,045 Baht per household.

For the risk of losing yield by 50 percent, the marginal value of this attribute is between 1.914 -1.926 Baht indicating that farmers would accept at least an increase in the price of rice by 1.914 to 1.926 Baht per Kilograms for an increase in one year of losing rice production by 50 percent. Again, we can use the same method to calculate the average total monetary value related to this risk. The average total monetary value related to the increase in number of years of losing yield is about 11,905-12,750 Baht per household per increased year, which means on average each household would require compensation of at least these amounts if switching from conventional rice practice to organic rice practice caused one year of losing yield by 50 percent.

Table A4.4 Monetary value elicited from farmer's choice experiment

Variable	Value (Baht per Kilogram)	
	Mix logit	Combining model
Availability of beneficial insects	-1.400***	-0.680*
	(-2.107 - -0.693)	(-1.487 - 0.126)
Risk of dying from pesticide poisoning	2.582***	2.278***
	(2.123 - 3.040)	(1.872 - 2.685)
Number of days PM2.5 exceeds standard level	0.158***	0.168***
	(0.101 - 0.215)	(0.103 - 0.233)
Number of years within the decade of losing	1.914***	1.926***
yield by 50 percent	(1.549 - 2.281)	(1.504 - 2.348)

Note: Numbers in parentheses present range of value at 95 confidence intervals. ***, **, and * represent significance levels at 1%, 5%, and 10%, respectively.

Appendix 5: Converting amount of PM2.5 to PM2.5 concentration

Converting PM2.5 from volume to concentration, we applied two steps. The first step is to estimate the atmospheric volume ($\boldsymbol{V_i}$). The average PM2.5 concentration in each province during December to April were calculated. The atmospheric volumes in each province were calculated from the dividing PM2.5 quantities by PM2.5 concentration according to the following equation:

$$V_i = Q_{ti}/C_{ti}$$

where V_i is atmospheric volume in province i

Q_{ti} is PM2.5 quantity in province i, year t

C_{ti} is PM2.5 concentration in province i, year t

For the second step, these atmospheric volumes (V_i) were used to project the future concentrations of PM2.5 for each province according to the four scenarios. The results, which predict the concentration of PM2.5 in the reference years, are shown in Tables A5.1-A5.4. For the BAU scenario, the concentration of PM2.5 is affected by the change to organic area in only three provinces, Khon Kaen, Buri Ram, and Nakhon Ratchasima. For the second scenario, two more provinces, Chaiyaphum and Maha Sarakham are expected to see farmers converting to organic between 2030 and 2035, resulting in a slight change in PM2.5 in 2035. Meanwhile, in the third and the fourth scenarios, there are significant reductions in the concentration of PM2.5 in the 20 provinces of the Northeast of Thailand.

Table A5.1 Projected PM2.5 concentrations resulting from rice residue burning in the BAU scenario (micrograms / cubic meter)

Provinces	2019	2025	2030	2035
Amnat Charoen	32.06	32.06	32.06	32.06
Bueng Kan	32.21	32.21	32.21	32.21
Buri Ram	35.35	32.81	32.81	32.81
Chaiyaphum	33.57	36.71	36.71	36.71
Kalasin	35.79	35.79	35.79	35.79
Khon Kaen	35.05	33.23	33.23	33.23

Provinces	2019	2025	2030	2035
Loei	44.27	44.27	44.27	44.27
Maha Sarakham	35.41	35.09	35.09	35.09
Mukdahan	18.66	18.66	18.66	18.66
Nakhon Phanom	15.66	15.66	15.66	15.66
Nakhon Ratchasima	36.40	33.39	33.39	33.39
Nong Bua Lam Phu	34.79	34.79	34.79	34.79
Nong Khai	15.06	15.06	15.06	15.06
Roi Et	44.31	44.31	44.31	44.31
Sakon Nakhon	35.74	35.74	35.74	35.74
Si Sa Ket	31.96	31.96	31.96	31.96
Surin	34.25	34.20	34.20	34.20
Ubon Ratchathani	30.49	30.49	30.49	30.49
Udon Thani	17.74	17.74	17.74	17.74
Yasothon	33.57	33.57	33.57	33.57

Table A5.2 Projected PM2.5 concentrations from rice residue burning in the second scenario (micrograms / cubic meter)

Provinces	2019	2025	2030	2035
Amnat Charoen	32.06	32.06	32.06	32.06
Bueng Kan	32.21	32.21	32.21	32.05
Buri Ram	35.35	30.92	30.92	27.21
Chaiyaphum	36.71	36.71	36.71	33.61
Kalasin	35.79	35.79	35.79	35.79
Khon Kaen	35.05	29.49	29.49	23.40
Loei	44.27	44.27	44.27	44.27
Maha Sarakham	35.41	32.33	32.33	18.45
Mukdahan	18.66	18.66	18.66	18.66
Nakhon Phanom	15.66	15.66	15.66	15.66
Nakhon Ratchasima	36.40	27.14	27.14	18.93

Provinces	2019	2025	2030	2035
Nong Bua Lam Phu	34.79	34.79	34.79	34.79
Nong Khai	15.06	15.06	15.06	15.06
Roi Et	44.31	44.31	44.31	42.57
Sakon Nakhon	35.74	35.74	35.74	35.74
Si Sa Ket	31.96	31.96	31.96	31.96
Surin	34.25	33.83	33.83	32.66
Ubon Ratchathani	30.49	30.49	30.49	30.49
Udon Thani	17.74	17.74	17.74	17.74
Yasothon	33.57	33.57	33.57	33.57

Table A5.3 Projected PM2.5 concentrations from rice residue burning in the third scenario (micrograms / cubic meter)

Provinces	2019	2025	2030	2035
Amnat Charoen	32.06	32.06	32.06	32.06
Bueng Kan	32.21	31.87	30.10	25.24
Buri Ram	35.35	24.29	12.58	2.86
Chaiyaphum	36.71	30.05	11.92	0.98
Kalasin	35.79	35.79	30.78	15.52
Khon Kaen	35.05	21.62	13.48	4.42
Loei	44.27	44.27	42.53	36.35
Maha Sarakham	35.41	13.66	0.31	0.00
Mukdahan	18.66	18.66	18.66	16.48
Nakhon Phanom	15.66	15.66	15.59	14.40
Nakhon Ratchasima	36.40	16.12	8.63	1.26
Nong Bua Lam Phu	34.79	34.79	34.79	34.79
Nong Khai	15.06	15.06	15.06	14.97
Roi Et	44.31	40.37	17.20	3.24
Sakon Nakhon	35.74	35.74	35.74	35.65

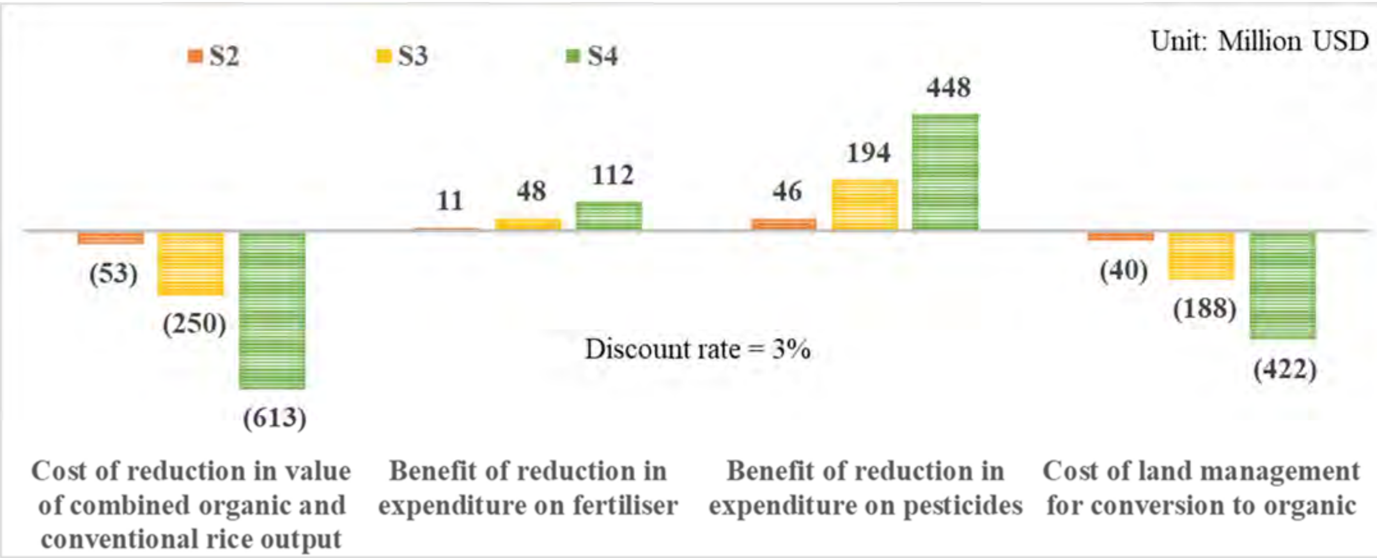
Provinces	2019	2025	2030	2035
Si Sa Ket	31.96	31.96	31.96	27.68
Surin	34.25	31.51	21.83	10.00
Ubon Ratchathani	30.49	30.49	30.49	30.16
Udon Thani	17.74	17.74	17.74	17.74
Yasothon	33.57	33.57	33.53	24.43

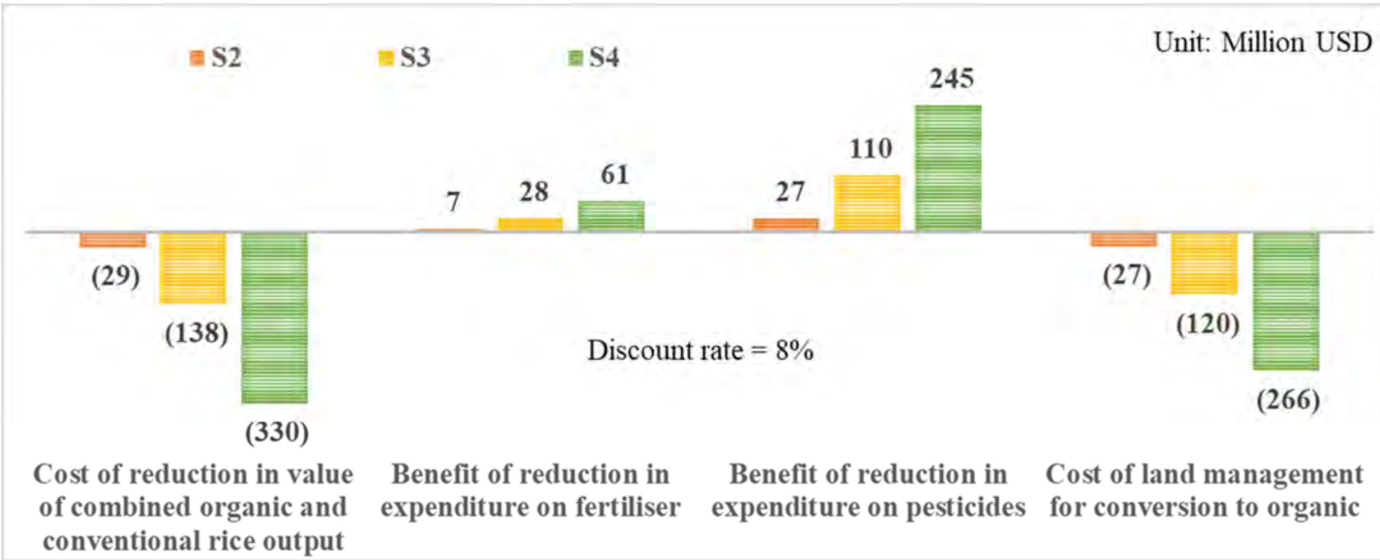
Table A5.4 Projected PM2.5 concentrations from rice residue burning in the fourth scenario (micrograms / cubic meter)

Provinces	2019	2025	2030	2035
Amnat Charoen	32.06	32.06	0.00	0.00
Bueng Kan	32.21	31.82	0.56	0.09
Buri Ram	35.35	23.58	0.00	0.00
Chaiyaphum	36.71	29.49	0.00	0.00
Kalasin	35.79	35.79	0.00	0.00
Khon Kaen	35.05	21.30	0.00	0.00
Loei	44.27	44.27	21.34	3.41
Maha Sarakham	35.41	12.80	0.00	0.00
Mukdahan	18.66	18.66	0.00	0.00
Nakhon Phanom	15.66	15.66	0.00	0.00
Nakhon Ratchasima	36.40	15.76	0.00	0.00
Nong Bua Lam Phu	34.79	34.79	0.00	0.00
Nong Khai	15.06	15.06	13.93	2.23
Roi Et	44.31	39.90	0.00	0.00
Sakon Nakhon	35.74	35.74	7.77	1.24
Si Sa Ket	31.96	31.96	0.00	0.00
Surin	34.25	31.27	0.00	0.00
Ubon Ratchathani	30.49	30.49	16.67	2.67
Udon Thani	17.74	17.74	9.70	1.55
Yasothon	33.57	33.57	0.00	0.00

Appendix 6: Tables of benefit-cost analysis

Figure A6.1 The total value of rice production and cost savings in each scenario from 2019 to 2035 compared to BAU.





APPENDIX 6 - Cost Benefit analysis figures at different discount rates

Figure A6.2 Financial analysis: Net present values projected from 2019 to 2035 in each scenario compared to BAU

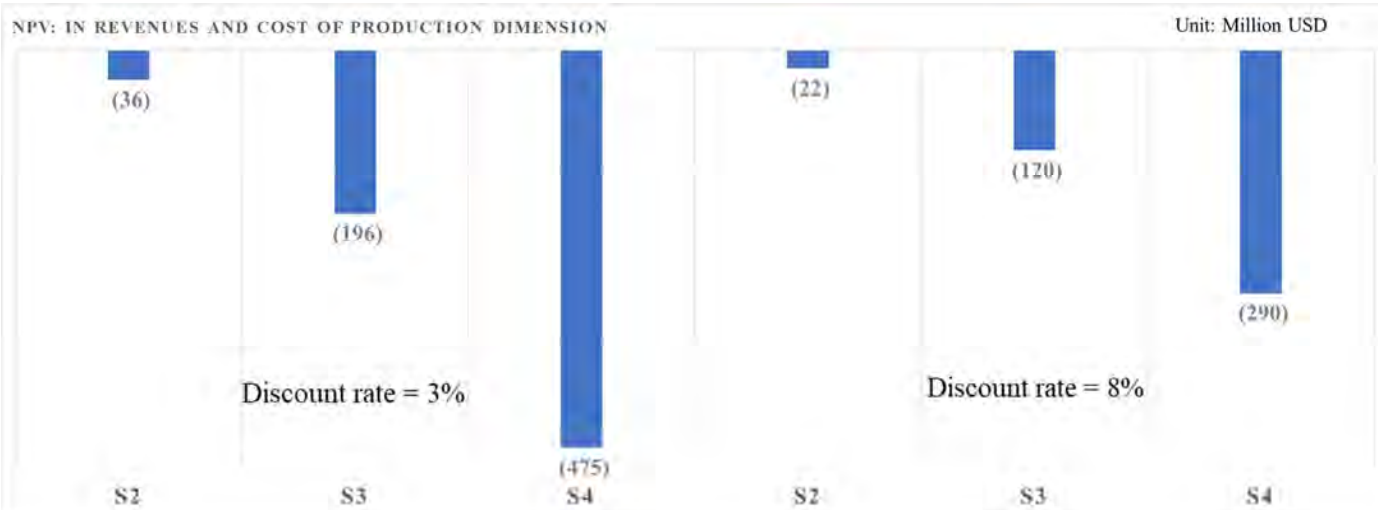


Figure A6.3 The values of health categorized by sources from 2019 to 2035 in each scenario compared to BAU

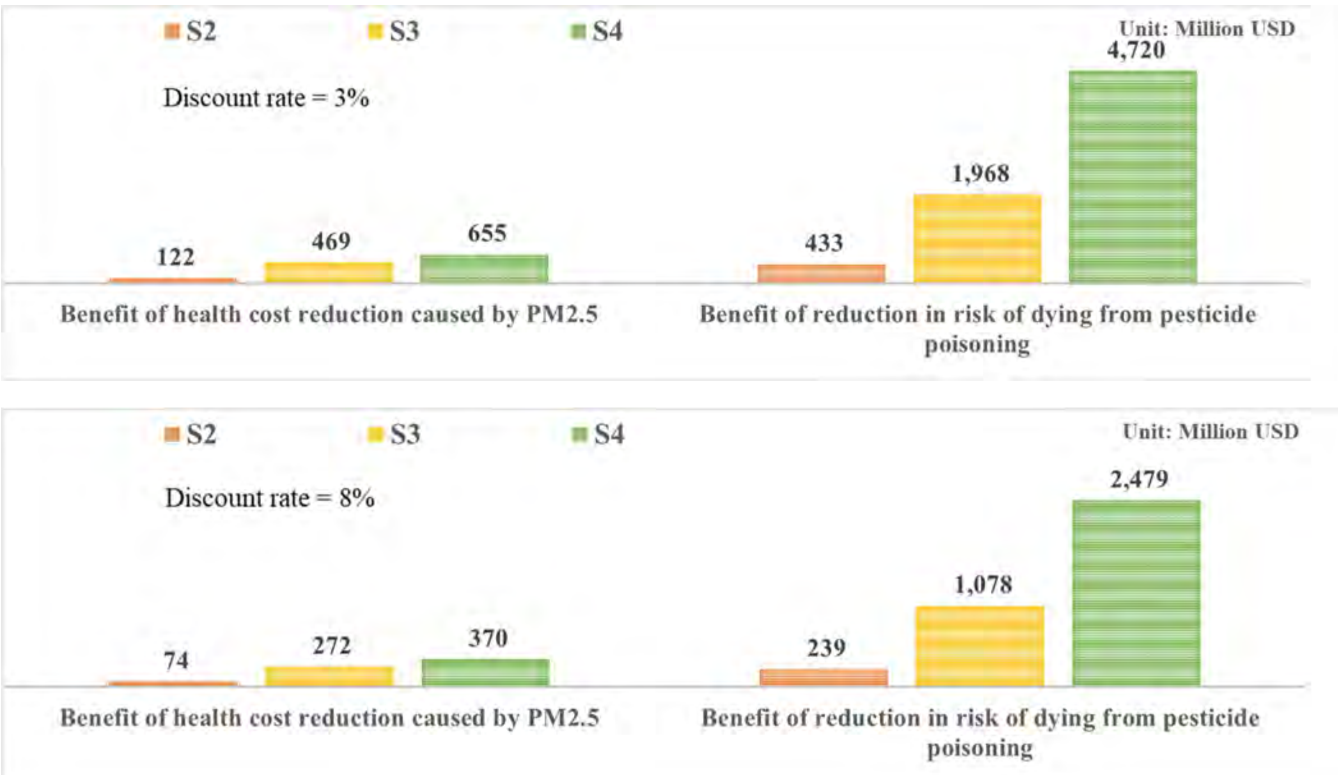
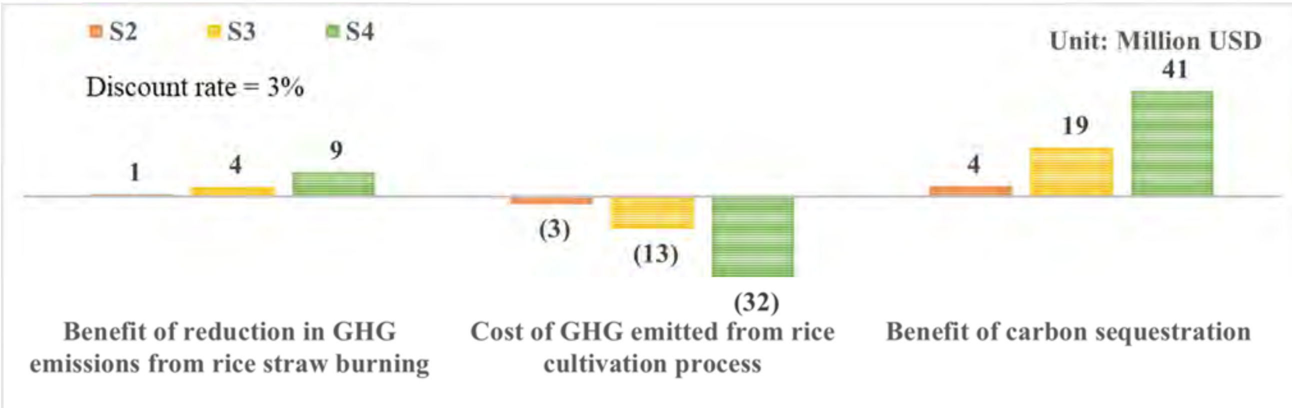
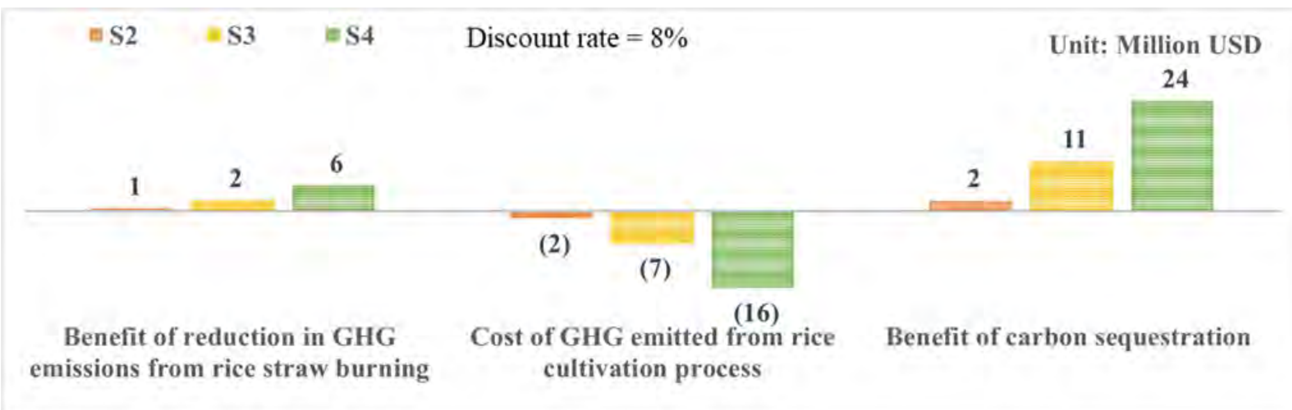


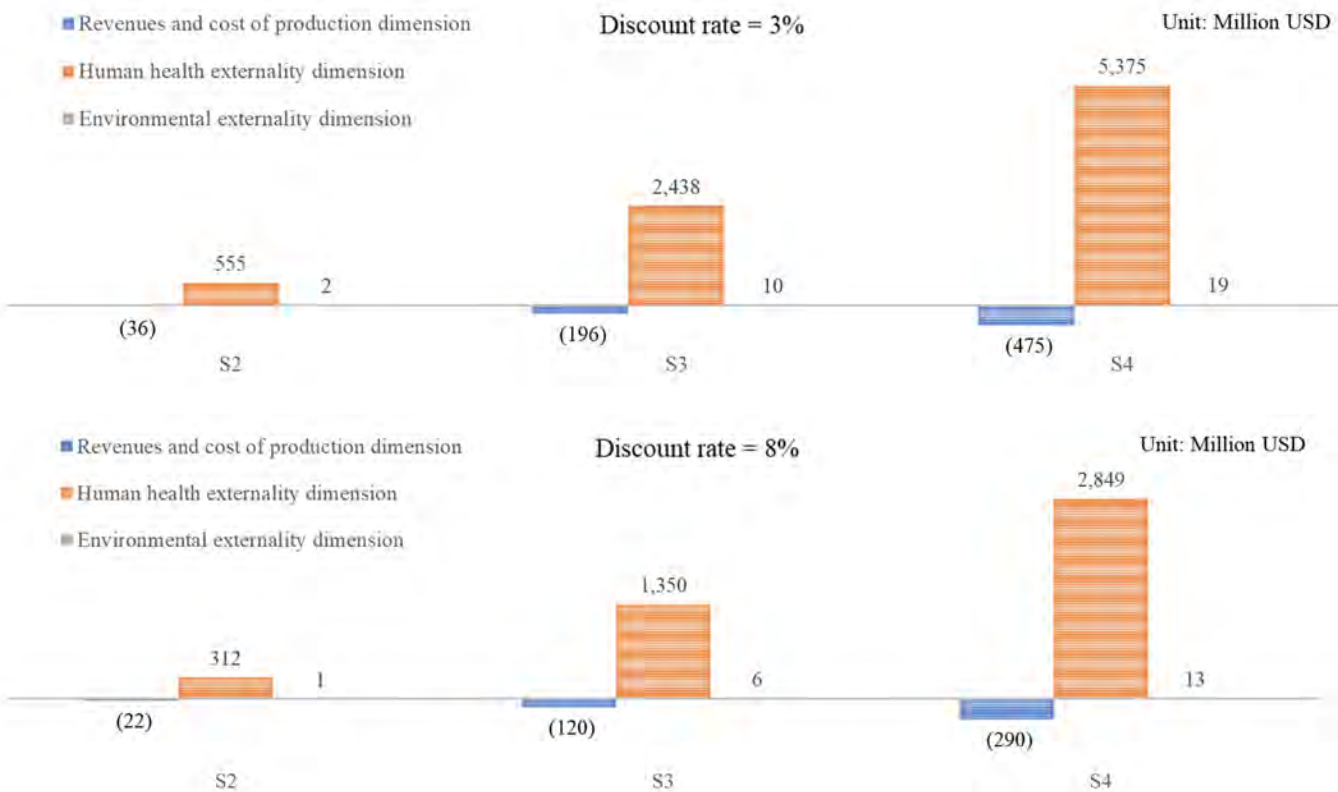
Figure A6.4 The values of GHG emissions categorized by sources from 2019 to 2035 in each scenario compared to BAU





APPENDIX 6 - Cost Benefit analysis figures at different discount rates

Figure A6.5 The positive and negative values of organic rice area expansion from 2019 to 2035 compared to BAU



APPENDIX 6 - Cost Benefit analysis figures at different discount rates

Figure A6.6 The net present value of organic area expansion from 2019 to 2035 in each scenario compared to BAU

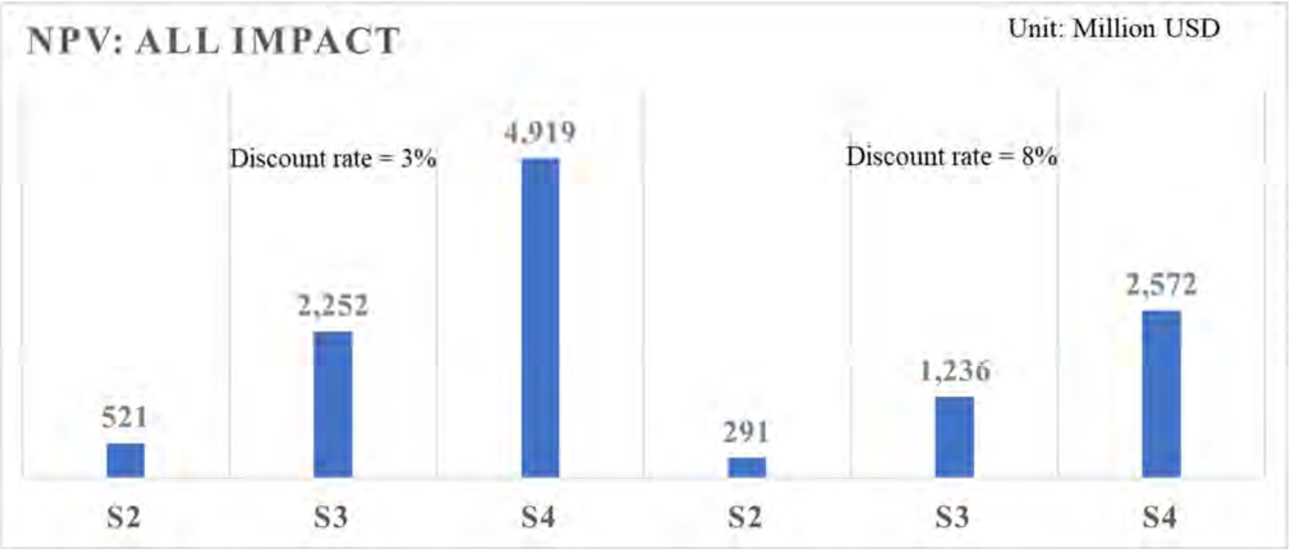


Figure A6.7 The value generated to farmers from organic rice area expansion from 2019 to 2035 in each scenario compared to BAU

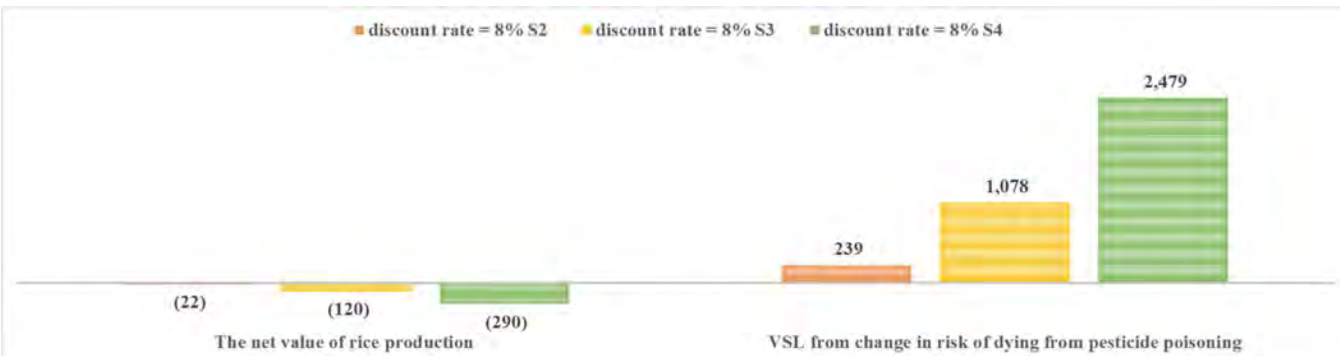


Figure A6.8 The value generated to public from organic rice area expansion from 2019 to 2035 in each scenario compared to BAU

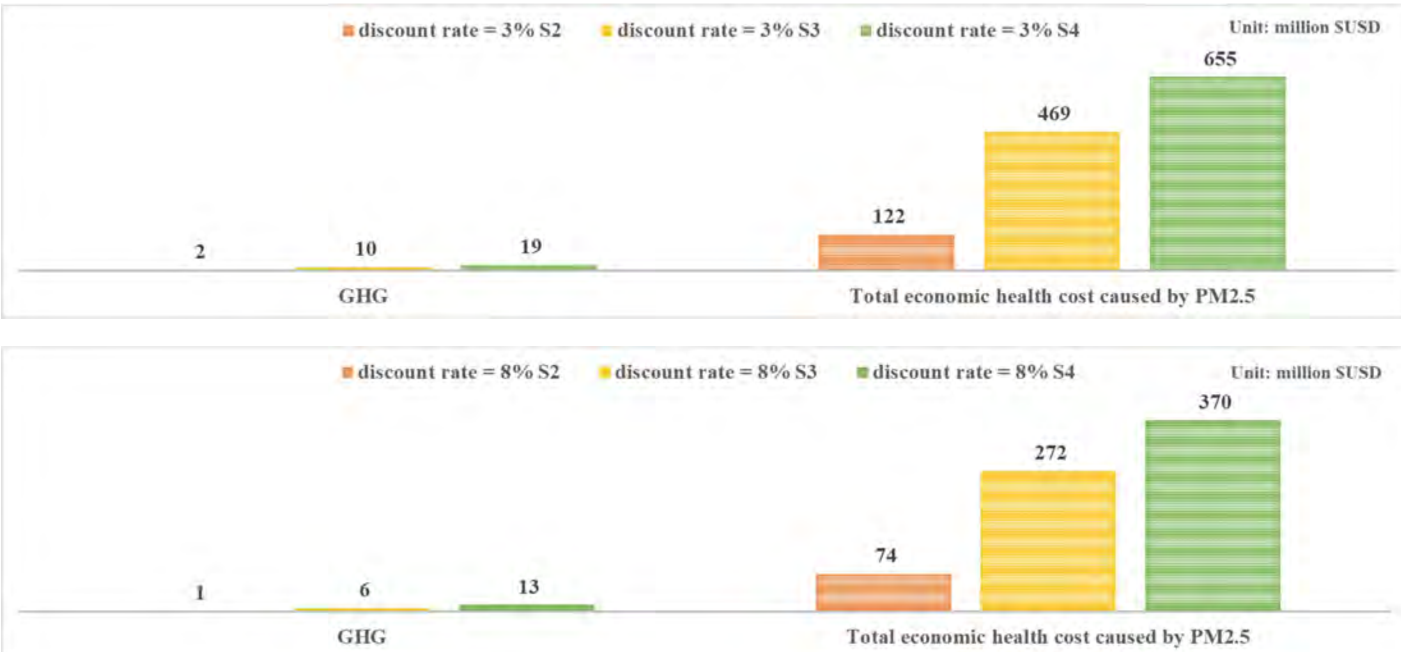
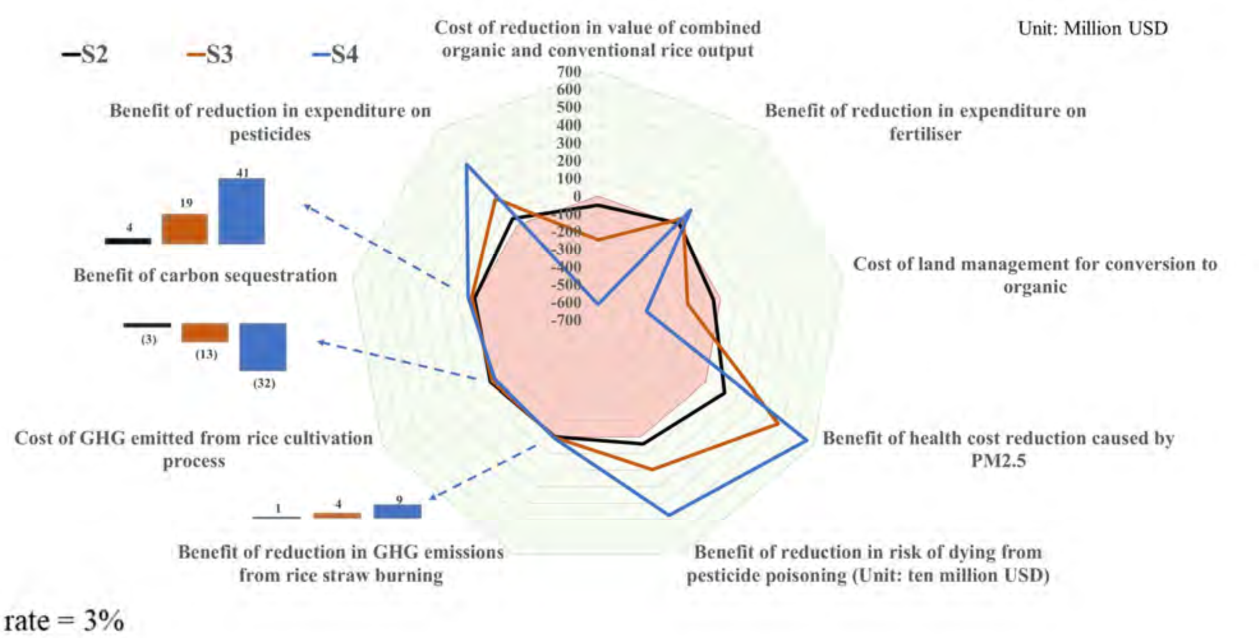
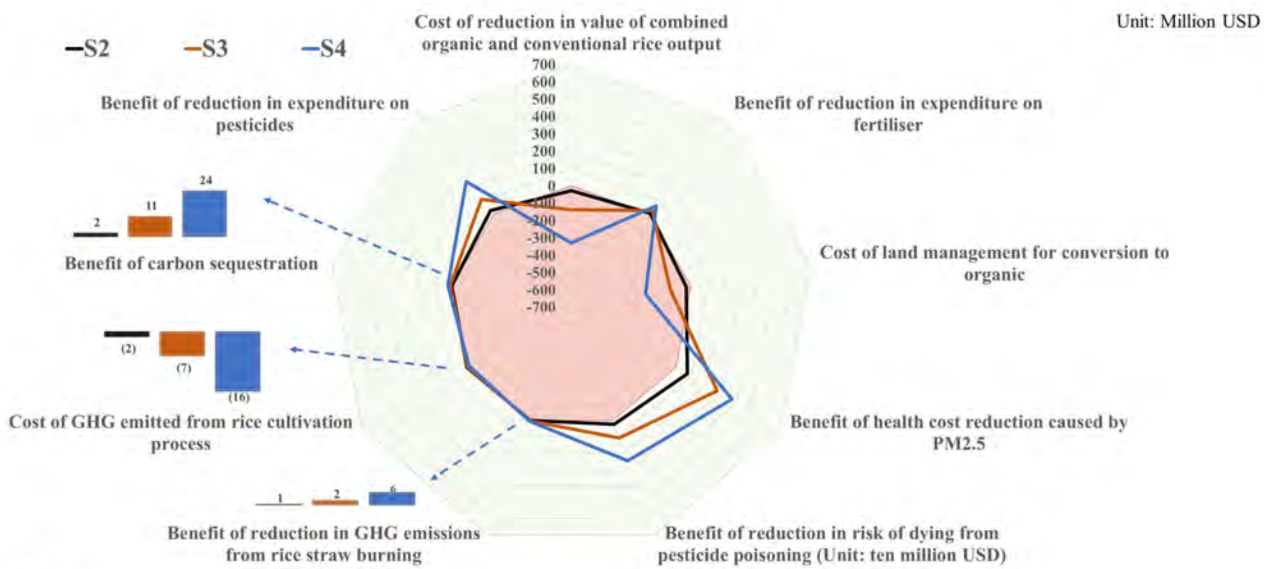


Figure A6.9 The scenario analysis based on values of all issue in each scenario compared to BAU

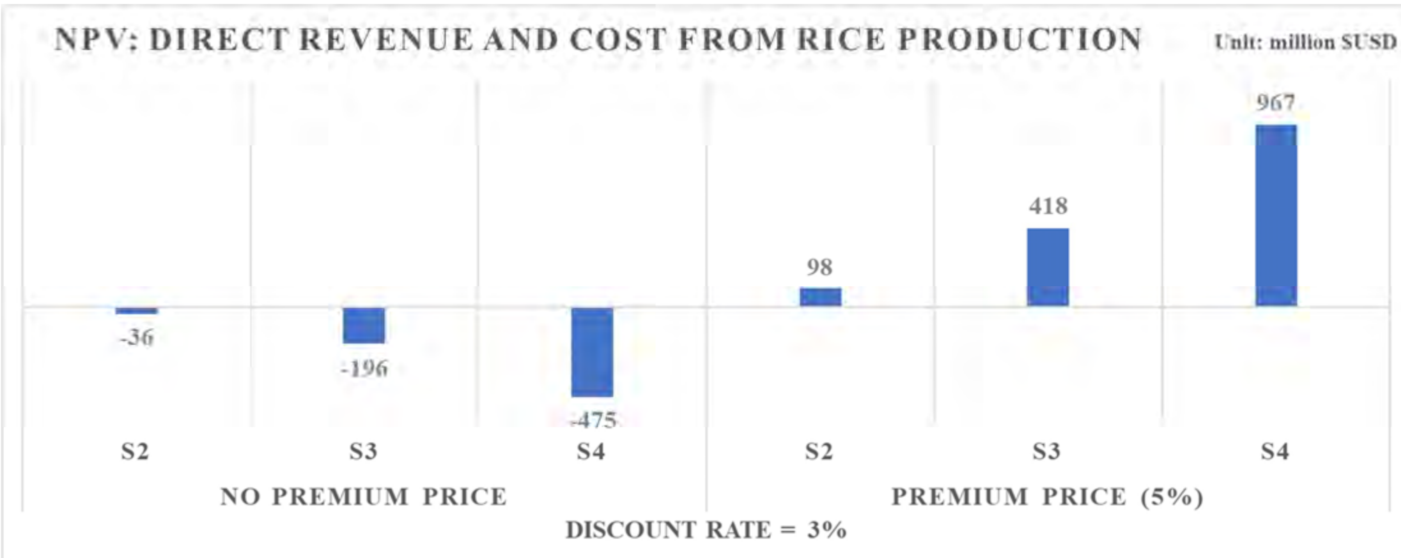


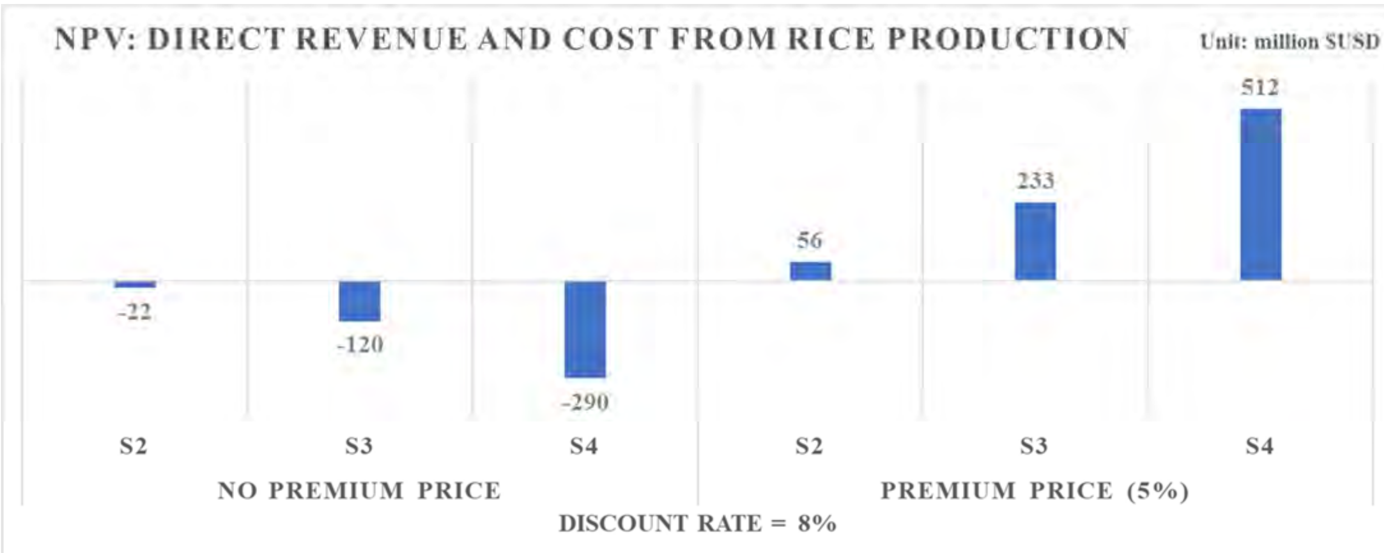


Discount rate = 8%

APPENDIX 6 - Cost Benefit analysis figures at different discount rates

Figure A6.10. The net revenue from organic production without premium price and with 5% premium price from 2019 to 2035 in each scenario relative to BAU





APPENDIX 6 - Cost Benefit analysis figures at different discount rates

Table A6.1. benefit-cost analysis

Direct value of rice production	discount rate = 3%			discount rate = 5%			discount rate = 8%		
	S2	**S3**	**S4**	**S2**	**S3**	**S4**	**S2**	**S3**	**S4**
The total value of rice production	-52,838,412	-249,601,820	-612,739,236	-41,552,744	-196,027,124	-476,351,224	-29,311,742	-137,994,443	-330,077,875
The total cost reduction of changing from conventional rice to organic rice	11,486,273	48,479,998	112,011,108	9,259,350	38,412,420	87,465,914	6,837,403	27,558,729	61,254,016
The total pesticide cost reduction of changing from conventional rice to organic rice	45,945,090	193,919,993	448,044,430	37,037,401	153,649,680	349,863,655	27,349,613	110,234,914	245,016,065
The total transferring cost from the conventional to organic rice (USD)	-40,381,790	-188,470,599	-422,438,779	-34,119,816	-156,093,120	-349,841,057	-27,092,369	-119,769,364	-266,406,578
NPV: Direct value of rice production	-35,788,839	-195,672,428	-475,122,478	-29,375,809	-160,058,144	-388,862,711	-22,217,095	-119,970,163	-290,214,372

Human	discount rate = 3%			discount rate = 5%			discount rate = 8%		
	S2	**S3**	**S4**	**S2**	**S3**	**S4**	**S2**	**S3**	**S4**
NPV: Direct value of rice production	-35,788,839	-195,672,428	-475,122,478	-29,375,809	-160,058,144	-388,862,711	-22,217,095	-119,970,163	-290,214,372
Total economic health cost caused by PM2.5	121,973,516	469,337,679	655,134,199	98,847,020	374,862,363	518,082,171	73,678,108	272,177,781	370,279,470
VSL from change in risk of dying from pesticide poisoning	432,933,475	1,968,370,296	4,719,597,705	338,993,628	1,537,509,709	3,628,237,829	238,522,004	1,077,844,497	2,479,146,662
NPV: Human	519,118,152	2,242,035,547	4,899,609,427	408,464,839	1,752,313,928	3,757,457,289	289,983,017	1,230,052,115	2,559,211,760

Natural	discount rate = 3%			discount rate = 5%			discount rate = 8%		
	S2	**S3**	**S4**	**S2**	**S3**	**S4**	**S2**	**S3**	**S4**
GHG emission value of air pollution due to rice straw burning	937,805	3,874,136	9,412,730	752,341	3,048,197	7,350,102	595,146	2,334,906	5,559,207
GHG emissions value from cultivation	-2,796,228	-12,514,852	-31,546,083	-2,184,969	-9,750,490	-24,191,924	-1,532,722	-6,809,736	-16,468,020
Value of soil carbon stocks	4,029,783	19,102,471	41,128,992	3,201,715	15,104,708	32,945,840	2,309,799	10,818,392	23,872,117
NPV: Natural	2,171,359	10,461,754	18,995,639	1,769,088	8,402,415	16,104,018	1,372,223	6,343,562	12,963,304

APPENDIX 6 - Cost Benefit analysis figures at different discount rates

Appendix 7: Household questionnaire

Available on request.