The Relationship Between Greenhouse Gas Emission and Rice Production in Thailand

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การเปลี่ยนแปลงภูมิอากาศ (Climate Change) สร้างความกังวลให้กับทั่วโลกมาหลายช่วงทศวรรษ ซึ่งมีสาเหตุมาจากกิจกรรมของมนุษย์ รวมถึงการปลูกข้าว ถึงแม้ว่ากิจกรรมทางการเกษตรจะปล่อยก๊าซเรือนกระจก แต่ก็มีความสำคัญต่อเศรษฐกิจไทยมานานเช่นกัน การศึกษานี้มีสองวัตถุประสงค์คือ เพื่อศึกษาความสัมพันธ์ระหว่างการผลิตข้าวต่อการปล่อยก๊าซเรือนกระจกในประเทศไทย ในประเมินความสมดุลระหว่างแง่มุมของเศรษฐกิจและธรรมชาติ และเพื่อศึกษาวิธีการบริหารนาข้าวที่สามารถสร้างความสมดุลระหว่างการลดการปล่อยก๊าซเรือนกระจกและรายได้จากการปลูกข้าว สำหรับวัตถุประสงค์แรก การศึกษานี้นำชุดข้อมูลทุติยภูมิแบบแผง จากปี พ.ศ. 2555 ถึง ปี พ.ศ. 2560 ระดับจังหวัดของประเทศไทยมาใช้ ในการสร้างแบบจำลองภายใต้การวิเคราะห์แบบ Panel Data Regression และ วิธีกำลังสองน้อยที่สุด 2 ขั้น (Two-Stage Least Squares) เพื่อรับมือกับปัญหาความสัมพันธ์สองทิศทางระหว่างตัวแปรต้นและตัวแปรตาม (Simultaneity Bias) จากการศึกษาพบว่าความสัมพันธ์ระหว่างการปลูกข้าวและปริมาณการปล่อยก๊าซเรือนกระจกต่อหัวในประเทศไทย เป็นตามรูปแบบตัว N และมีความสัมพันธ์เชิงสาเหตุและผลลัพธ์ในทิศทางเดียวคือ จากการปลูกข้าว สู่ปริมาณ ก๊าซเรือนกระจกต่อหัว นอกจากนี้ ยังพบว่าความหนาแน่นของประชากรและปริมาณการบริโภคน้ำมันเชิงพาณิชย์ขั้นสุดท้ายจะมีความสัมพันธ์เชิงบวกกับปริมาณก๊าซเรือนกระจกต่อหัว ในขณะที่ปริมาณก๊าซเรือนกระจกต่อหัวมีแนวโน้มลดลงตามเวลาในแต่ละปี จากรูปร่างความสัมพันธ์ระหว่างการลดลงของปริมาณก๊าซเรือนกระจกต่อหัวจากการปลูกข้าวนั้น เป็นเพียงแนวโน้มชั่วคราว และการปลูกข้าวเพิ่มขึ้นจะทำให้ปริมาณการปล่อยก๊าซเรือนกระจกต่อหัวมีปริมาณมากขึ้นในที่สุด สำหรับวัตถุประสงค์ที่สอง จากการทบทวนวรรณกรรมอย่างเป็นระบบ (Systematic Review) พบว่า งดการไถพรวนดิน การใช้ปุ๋ยไนโตรเจน และ การเลี้ยงสัตว์ในนาข้าว สามารถสร้างสมดุลระหว่างแง่มุมของเศรษฐกิจและธรรมชาติได้ ในขณะเดียวกันยังมีการบริหารนาข้าวในรูปแบบอื่นๆ เช่น ปุ๋ยละลายช้า และ ถ่านชีวภาพ ที่สามารถลดการปล่อยก๊าซเรือนกระจกได้มากกว่า แต่มีราคาที่สูงเกินกว่าจะสร้างผลกำไรให้กับชาวนา ดังนั้นรัฐบาลควรเข้าแทรกแซงราคาเพื่อให้ชาวนาสามารถนำสินค้าเหล่านี้ไปใช้ได้ เพื่อให้เกิดผลกระทบที่ดีต่อสิ่งแวดล้อม

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Climate Change has been a global concern for decades. The phenomenon is mainly caused by human activities, including rice production. Although the agricultural activity can adversely emit greenhouse gas emission, it is also vital to Thai economy for a long time as well. This study has two objectives. The first objective is to examine the relationship between greenhouse gas emission and rice production in Thailand to evaluate the balance between economic and environmental aspects. The second objective is to study rice farming practices that can balance between greenhouse gas emission mitigation and rice farmers' income. For the first objective, secondary, panel dataset from 2012 to 2017 at provincial level of Thailand is applied in Panel Data Regression Models, and Two-Stage Least Squares (TSLS) is also utilized to cope with potential two-way causality between rice production and emission. This study found that the variables are in N-shaped relationship, and only one-way casual effect from rice production to greenhouse gas emission is found. Additionally, while population density and final commercial energy consumption from oil are found to be positively related to greenhouse gas emission per capita, time trend shows a negative relationship with the emission. The N-shaped relationship suggests that a decrease greenhouse gas emission from rice production is only temporary as further growth will lead to higher emission. For the second objective, from systematic review, this study suggests no tillage, nitrogen fertilizers, and integrated rice-animal farming as alternative rice farming practices that can balance between economic and environmental aspects for rice production. Meanwhile, some practices such as slow-release fertilizer and biochar can generate even less greenhouse gas emission, but they are not economically profitable. Thus, the government should control their prices to make them profitable for farmers as they can generate positive externality to the environment.

Field of Study:	Business and Managerial Economics	Student's Signature ....
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CHAPTER I INTRODUCTION

1.1 Background and Significance of the Problem

Significance of climate change problems can be noticed from wide range of destructive phenomenon in various aspects. It is worth to note that even the global is expected to increase by 3-degree Celsius doubling what climate experts have informed to evade serious economic, social and environmental consequence. Ecosystems stress clearly expresses through warmer ocean, melting glaciers, and loss of biodiversity. Economic stress is measured as the loss of USD 165 billion worldwide from natural disasters in 2018. Capital market is at risk. The examples are the wider of catastrophe protection gap which make the damage unaffordable to be insured, or disruption of mortgage market on the moderate-to-high-risk area. For businesses, trade, labor and supply chain are severely disturbed such as rising of sea-level-route, shifting of seasonable temperature and rainfall which worsens agricultural yields, and impacts of heat stress to labor force (World Economic Forum, 2020).

To tackle with climate change downsides, agreements, cooperation and non-monetary trade barriers are potentially strengthened to alleviate the problems. To meet the qualification and being accepted as an environmentally friendly company, the firm does not only need to improve itself but also to evaluate its whole supply chain. There are many ways the firm can apply to reduce greenhouse gas emission. For examples, the firm can use the alternative energy for transportation and production process. Innovative technology and machines consuming less energy can also be installed. Waste reduction and sequestration system can help to lower the amount of greenhouse gas emission. For the food production, it is undeniable that agricultural businesses such as farming and raising livestock is included as a vital, starting node of supply chain. Not only important as a part of the business, farming and livestock also serve as a safety net sector for job and food security in Thailand.

In agricultural sector of Thailand, rice is one of most important crops contributing to both economic and environmental aspects.

From 2017 to 2020, rice was one of top exported agricultural products for Thailand. In 2018 and 2019, for 2 consecutive years, it ranked as the 1st exported products under agricultural category with the value of 182,081.67 and 130,584.56 million baht, respectively (Ministry of Commerce, 2021). Additionally, the country was ranked as the 6th biggest milled rice producer in the world as shown in table 1. On average, the production of the country accounts for almost 4% of world total production, following China, India, Bangladesh, Indonesia, and Vietnam. However, the negative growths for the last 2 years can be clearly observed with -1.2% and -13.2% in 2019 and 2020, respectively.

Table 1 Top 6 Milled Rice Producers in the world from 2017 to 2020

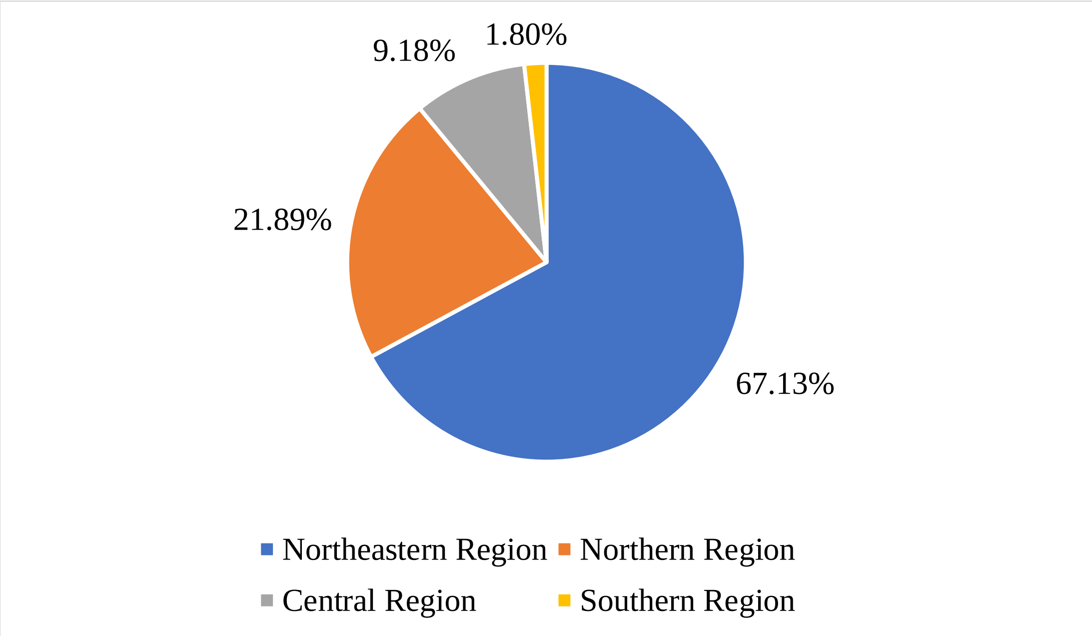
Unit: Metric tons

Country	**Year**			
	2017	**2018**	**2019**	**2020**
China	147.77	148.87	148.49	146.73
India	109.70	112.76	116.48	118.43
Bangladesh	34.58	32.65	34.91	35.85
Indonesia	36.86	37.00	34.20	34.00
Vietnam	27.40	27.66	27.34	27.10
Thailand	19.20	20.58	20.34	17.66
Others	116.24	114.92	115.56	116.63
World Total	**491.75**	**494.44**	**497.32**	**496.40**

Source: Thai Rice Exporters Association (2021)

Not only as the top exported agricultural product, rice is also vital sources of incomes for millions of households. In 2019, more than 4.4 million households cultivate in-season rice as a part of their livings. More than two-third are in Northeastern region of the country, followed by Northern, Central, and Southern regions of Thailand as shown in figure 1.

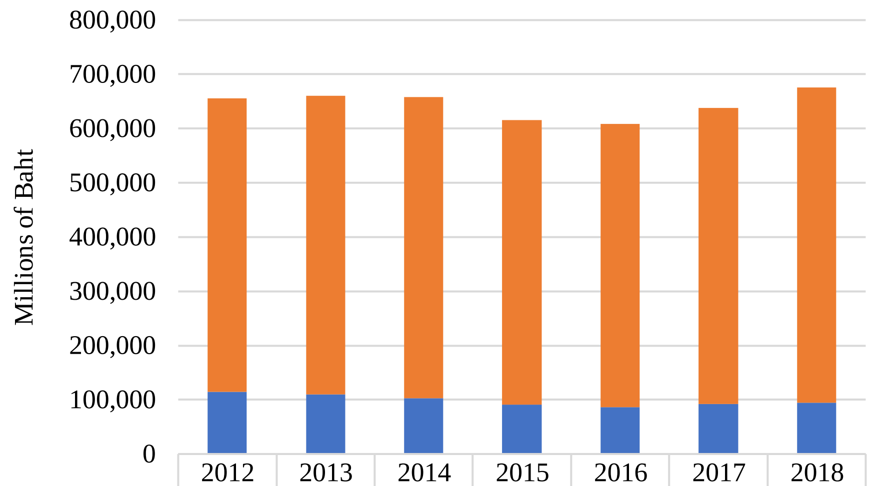
Figure 1 Proportion of households for in-season rice production of Thailand in 2019 classified by regions



Source: Office of Agricultural Economics of Thailand (2021)

As a part of domestic Thai economy, rice production also reflects its importance through a substantial contribution in agricultural sector. In term of real production value by Chain Volume Measures (CVM) with 2002 as a reference year, rice accounts for 14.04%-17.39% of total value from agricultural sectors over the years from 2012 to 2018 as shown in figure 2. Although the rice production value had shrunk from 114,064 million baht in 2012 to 86,150 million baht in 2016 or a decrease in 24.47% over 5 years, a gradual recovery can be seen as the value was back to 94,816 million baht in 2018.

Figure 2 Proportion of real rice production value in agricultural sector of Thailand from 2012 to 2018



	2012	2013	2014	2015	2016	2017	2018
Other Agricultural Products	541,694	551,046	555,148	525,420	522,603	545,353	580,521
Rice	114,064	109,319	103,315	90,463	86,150	92,753	94,816

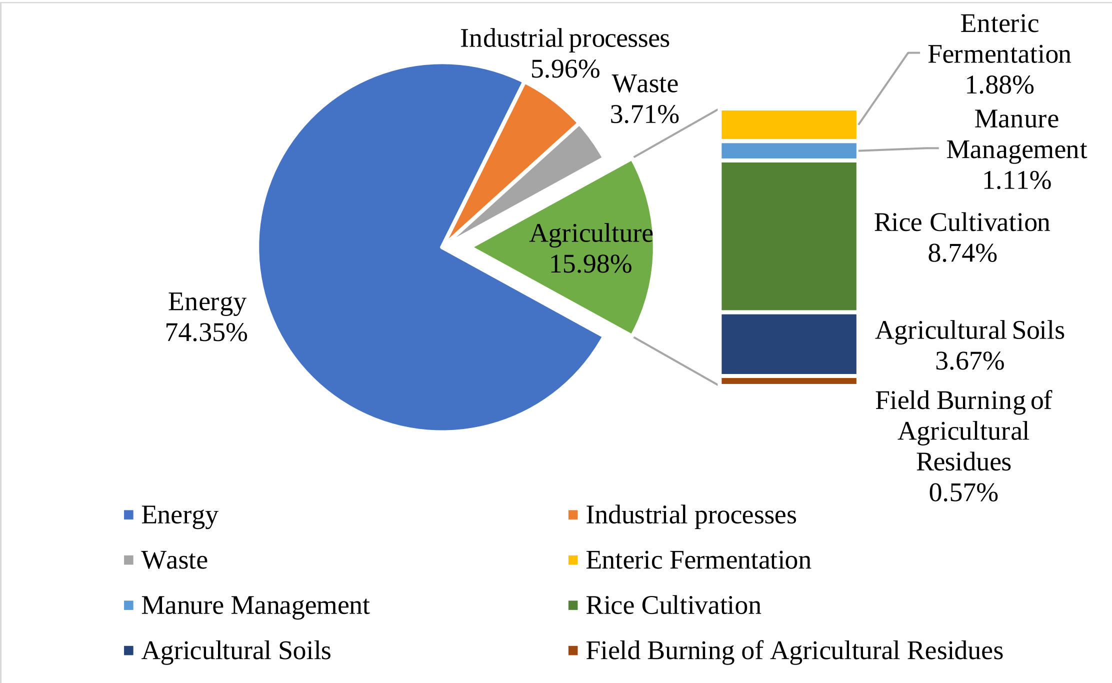
Source: Office of The National Economic and Social Development Council (NESDC) (2021)

Even though a growth in rice production is beneficial to the economy, food security, and labor market, without proper controls, it can adversely contribute to the global warming phenomenon. Intergovernmental Panel on Climate Change (IPCC) (1996) listed rice cultivation to be one of the main sources of anthropogenic greenhouse gas emission. Rice cultivation usually emits methane (CH_4) which is one of greenhouse gas emission. Intergovernmental Panel on Climate Change (IPCC) (2014) stated that in fact, over a time span of 100 years, Global Warming Potential (GWP) value of CH_4 is 28 times greater than that of Carbon Dioxide (CO_2). Moreover, rice cultivation indirectly causes Nitrous Oxide (N_2O) and CO_2 emission via the use of chemical fertilizer and machines for production.

Intergovernmental Panel on Climate Change (IPCC) (2001) estimated that considering CH_4 emission from rice fields in the world, rice cultivation in Thailand contributed up to 6.5% of total emission.

To the total of national greenhouse gas emission in 2013, rice cultivation was the biggest contributor under agricultural sector as shown in figure 3. It released 27,862.90 gigagrams of carbon dioxide equivalent ($GgCO_2eq$) which is equal to 8.74% of total national emission in that year.

Figure 3 Total greenhouse gas emission of Thailand by sector in 2013



Source: Office of Natural Resources and Environmental Policy and Planning (2015)

The relationship between rice cultivation and climate change is even more complicated as it is bidirectional. While the agricultural activity emits large amount of greenhouse gas as a byproduct causing climate change phenomenon, the climate change also takes its toll on the agricultural production's yield and quality through higher frequency of disasters and changing weather.

Well aware of the contribution to climate change and importance of rice cultivation to Thai economy, Ministry of Agriculture and Cooperatives (2012) issued the strategic plan for agricultural sector to tackle with the climate change from 2013 to 2016. The plan aims to increase farmers' incomes by improving production efficiency to become more environmentally friendly in various ways such as selling low-carbon products or reducing greenhouse gas emission. However, some researchers have shown that economic growth in agricultural sector is not simultaneously achievable with an improvement in environmental quality. For example, Zafeiriou, Sofios, and Partalidou (2017) has found that adoption of environment-friendly farming practices and crops' selection does not secure simultaneous economic growth in agricultural sector and improvement in environmental quality for Bulgaria, Czech Republic, and Hungary.

This study, therefore, has two objectives. First, the study aims to examine the relationship of rice production and greenhouse gas emission in Thailand to evaluate if the growth of rice production in the past was environmentally friendly in term of the contribution to the climate change.

Secondly, as climate change has become bigger concern throughout the world, and it is possible that, in the future, Thai government will potentially implement policies to restrict or control greenhouse gas emission from any activity, including rice cultivation. Nevertheless, in another perspective of rice farmers, the government policy is considered as a major, external factor which must be complied with and can affect strategic management of agribusiness (C.-C. Chen, Yueh, & Liang, 2016). Rice farmers, alike other businesses, also concern for profits which may be affected by the government policies. Therefore, the farmers should proactively prepare themselves to comply with stricter environmental policies while sustaining the bottom line of their businesses. This leads to the second objective of this study which is to study and gather information about agricultural practices in rice cultivation that can mitigate greenhouse gas emissions and simultaneously benefit farmers' incomes.

1.2 Research Question

How can the growth of rice production in Thailand balance between sustainability in term of climate change contribution and farm income?

1.3 Objectives of the Study

- To examine the relationship between greenhouse gas emission and income from rice production of Thailand
- To study and gather information about greenhouse gas mitigation practices in rice production which can simultaneously benefit to farm income.

1.4 Scope of the Study

A dataset of annual, provincial data in Thailand from 2012 until 2017 is used as a secondary data to find the relationship between value added of rice production to GPP (Gross Provincial Product) and greenhouse gas emission per capita.

Past related literatures which concern rice field management practices simultaneously mitigating greenhouse gas emission and sustaining farm income are reviewed.

1.5 Research Methodology

In order to achieve the first objective, panel regression analysis is the main tool to examine the relationship between greenhouse gas emission per capita and rice production value in Thailand.

For the second objective, systematic review is applied to study about the rice field management practices to mitigate greenhouse gas emission and sustain farm income.

1.6 Research Contribution

The result from this study is expected to be helpful in managing rice fields and designing agricultural policies to effectively mitigate greenhouse gas emission from the agricultural sector while sustaining or even increasing farm income.

CHAPTER II RICE PRODUCTION AND GREENHOUSE GAS EMISSION IN THAILAND

2.1 Rice Production in Thailand

Merriam-Webster defines rice as “the starchy seeds of an annual southeast Asian cereal grass (Oryza sativa) that are cooked and used for food”. In Thailand, the most popular rice cultivar is Jasmine rice, accounting for over 36% of total rice quantity produced in 2017 (Office of Agricultural Economics of Thailand, 2018).

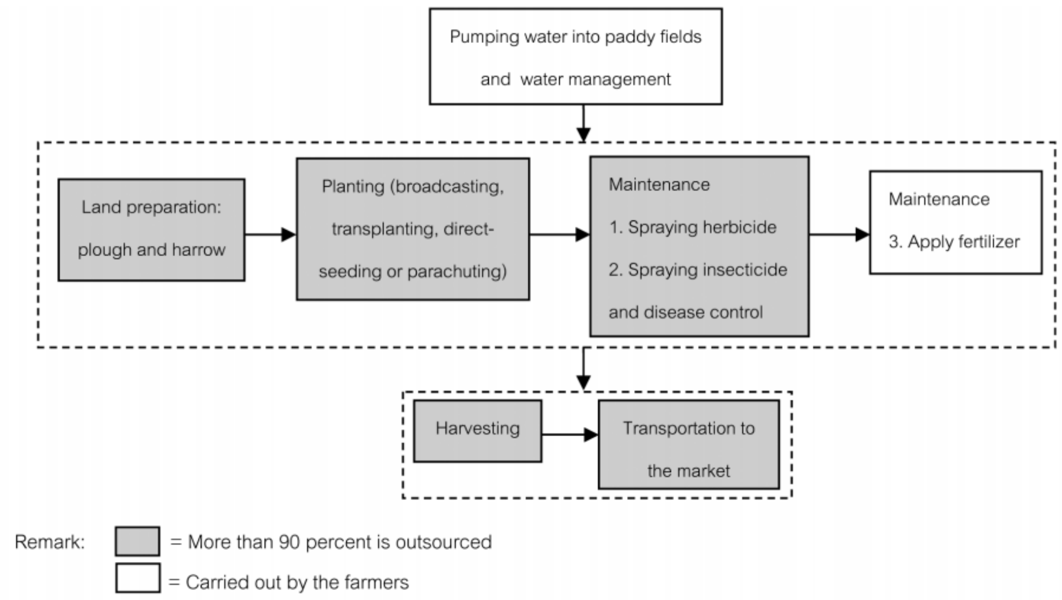
Another interesting characteristic of rice production in Thailand is irrigation system. Vongvisessomjai has stated numerous irrigation projects around Chao Phraya River. Royal Irrigation Department of Thailand (2020) has identified 22 provinces to be in Chao Phraya Basin, mostly in Lower Northern and Central regions, which are Tak ,Phichit, Sukhothai, Kam Phaeng Phet ,Phitsanulok ,Nakhon Sawan ,Uttaradit ,Ang Thong, Lop Buri ,Chai Nat ,Singburi ,Saraburi ,Suphan Buri ,Phra Nakhon Sri Ayuthaya ,Pathum Thani ,Nonthaburi ,Nakhon Pathom ,Chachoengsao ,Nakhon Nayok ,Samut Prakan, Samut Sakhon ,and Bangkok. As these provinces are located in the basin area, they tend to have relatively larger proportion of irrigated rice fields than other provinces. As a result, the rice production is likely to be more productive because of better water management. It also enables farmers to produce rice more than once a year.

There are numerous rice cultivation methods. Rice cultivation can be classified by 2 main characteristics: cultivated area and season. Classified by the characteristics of cultivated area, there are 3 main types in Thailand. The first type is upland rice. It usually takes place on plateau and does not require much water relatively to other cultivated areas. The type of paddy rice can be found throughout many regions: northern, eastern, northeastern, and southern regions. However, it accounts for only 10% of rice paddy in Thailand. Next is lowland rice where the paddy is mostly flooded throughout the cultivation since planting, except when harvested. Lowland rice is the most popular method in the country, accounting for

80% of total rice paddy. The last type is floating rice accounting for 10%. It is usually applied where water level cannot be controlled. Meanwhile, if classified by season, there are in-season and off-season rice cultivations. In-season rice cultivation usually starts in the period between May and October. The final harvest is no later than February. Off-season rice cultivation usually starts in January and is popular where there is an irrigation, for example, in central region. (Chaipattana Foundation)

Although rice cultivation techniques are diversified, they share some similar activities. Nuntapanich (2015a) studied rice cultivation process under irrigation in Pichai and Tron districts, Uttradit province, Thailand. As shown in figure 4, the first step is water management which is pumping water into paddy fields. Next, farmers need to prepare land, involving soil management such as ploughing. Rice is then planted into the fields. This can be done by various methods such as broadcasting and parachuting. After that, it comes to maintenance phrase when herbicide, insecticide, and fertilizer are applied. The last steps are to harvest and transport to the market for sale. Similarly, Nuntapanich (2015b) lists rice cultivation activities under rainfed in Surin Province: land preparation, direct seeding, crop management, weeding, fertilizer applications, harvesting, and rice stubble burning. Despite different water management, land preparation is in initial stage followed by seeding. Crop management, weeding, and fertilizers are to maintenance rice paddy. Eventually, rice is harvested. An additional step is post-harvested activity to handle rice stubble or straw.

Figure 4 Rice cultivation process in irrigated area done by rice farmers in Pichai and Tron districts, Uttradit province

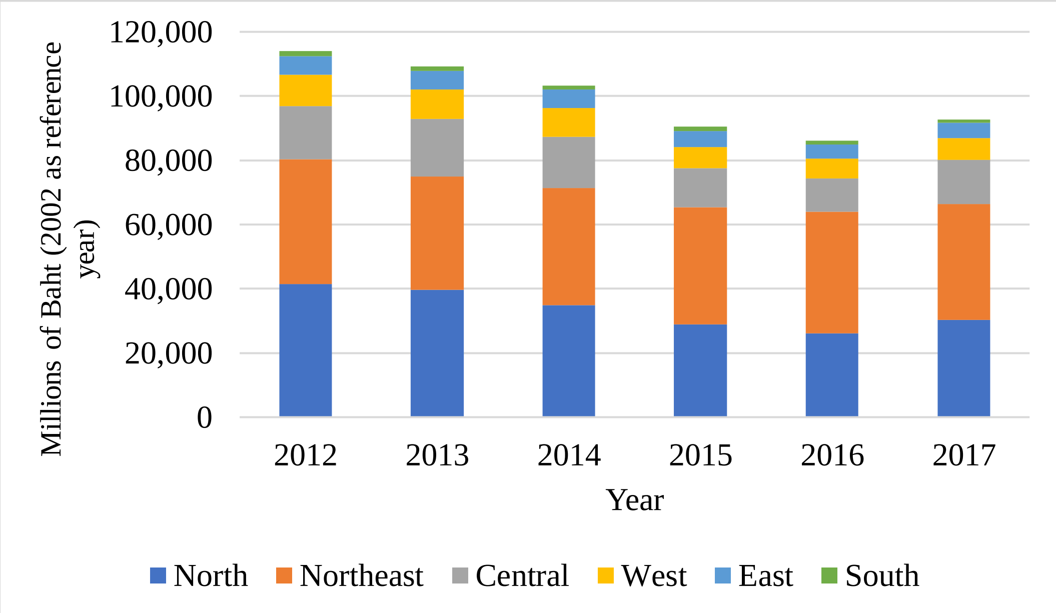


Source: Nuntapanich (2015a)

The yield from rice cultivation depends on many production factors. Like other products, rice production is based on fundamental production factors which are land, labor, capital, and entrepreneurship. Nuntapanich (2015a) lists detailed rice production factors which are proportion of rice cultivation to total agricultural land, objective of rice farming, rice farming area per household, rice varieties, farming practices, labor from both human and machine, seed rate, fertilizer application, pest controls and eradication, number of crops per year, and water management. Similarly, Pudaka, Rusdarti, and Prasetyo (2018) includes land size, seedlings, fertilizer, pesticide, and labor hour as production factors.

For overall situation of rice production in Thailand, the national real rice production value had been decreasing from 2012 to 2016 as shown in figure 5. Over 5 years, the value had declined from over 110,000 million baht to below 90,000 million baht. Nevertheless, in 2017, the total value has been recovered by over 7.5%. The contributions from regions are quite consistent over years. Northern, northeastern, and central regions are 3 regions with the highest rice production values. Over the 6 years, northeastern and northern regions account for 37.5% and 33.5% on average, respectively, followed by Central region with the average annual contribution of 14.5%. South region has the least rice production value among all regions with the average annual value of 1,327.96 million baht.

Figure 5 Rice production value as CVM by regions from 2012 to 2017



Source: Office of The National Economic and Social Development Council (NESDC) (2021)

Top 10 provinces with the highest rice production value in 2017 are listed in table 2 below. Most of the provinces are in either northern or northeastern regions, except Suphan Buri and Phra Nakhon Sri Ayuthaya in western and central regions, respectively. Nakhon Sawan in northern region has the highest production value of over 4,700 million baht or equal to 5.2% of national production. Combining the production value from top 10 provinces, it accounts for 39% of national production in 2017. Additionally, top 40 provinces have covered about 90% of national production. It is also worth to note that the top provinces and their contributions for the years from 2012 to 2016 are also similar to that of 2017. Table 3 lists 10 provinces with the lowest rice production value in 2017. Each province contributed much less than 1% of national value, and 8 out of 10 provinces are in southern region. Phuket is the province with the least production value in the country.

Table 2 Top 10 provinces with the highest rice production value in 2017

Rank No.	**Provinces**	**Region**	**Rice Production Value (million baht with 2002 as a reference year)**	**Cumulative percentage (%)**
1	Nakhon Sawan	North	4,785.49	5.2%
2	Suphan Buri	West	4,632.32	10.2%
3	Phichit	North	3,960.39	14.4%
4	Ubon Ratchathani	Northeast	3,770.98	18.5%
5	Phitsanulok	North	3,586.03	22.4%
6	Nakhon Ratchasima	Northeast	3,278.15	25.9%
7	Kam Phaeng Phet	North	3,157.59	29.3%
8	Surin	Northeast	3,071.15	32.6%
9	Roi Et	Northeast	3,003.93	35.8%
10	Phra Nakhon Sri Ayuthaya	Central	2,930.91	39.0%
Others			56,575.59	61.0%
Total			92,752.52	100.0%

Source: Office of The National Economic and Social Development Council (NESDC) (2021)

Table 3 10 provinces with the lowest rice production value in 2017

Rank No.	Provinces	Region	Rice Production Value (million baht with 2002 as a reference year)
1	Phuket	South	0.08
2	Ranong	South	0.52
3	Phangnga	South	1.63
4	Krabi	South	4.05
5	Chumphon	South	4.78
6	Samut Songkhram	West	6.59
7	Surat Thani	South	10.65
8	Trang	South	12.08
9	Yala	South	15.16
10	Chanthaburi	East	15.61

Source: Office of The National Economic and Social Development Council (NESDC) (2021)

2.2 Greenhouse Gas in Thailand

Intergovernmental Panel on Climate Change (IPCC) (2019) defines greenhouse gas as "gases in the atmosphere such as water vapour, carbon dioxide, methane and nitrous oxide that can absorb infrared radiation, trapping heat in the atmosphere". Although the gases can be emitted from nature, a sharp increase of greenhouse gases in recent decades is emitted from human activities, causing climate change. Under Kyoto Protocol, United Nations (1998) has focused on 6 greenhouse gases mitigation, which are carbon dioxide (CO_2), methane (CH_4), nitrous oxide (N_2O), hydrofluorocarbons (HFCs), perfluorocarbons (PFCs), and sulphur hexafluoride (SF_6). When measuring different greenhouse gases together, they are usually measured in a term of CO_2 equivalent calculated by the amount of emission multiplied by Global Warming Potential (GWP) value for each type of greenhouse gas emission (United States Environmental Protection Agency, 2021).

Greenhouse gases have different time remaining in the atmosphere and different contributions to the greenhouse effect, so an index called GWP is used to compare different types of greenhouse gases. Table 4 lists examples of GWP values. By comparison, CO_2 is used as a benchmark with the value of 1 to compare the effect on the climate change. From the table, given the same amount of gas, CH_4 and N_2O contributes to the climate changes 28 and 265 times, respectively, more than CO_2 over a period of 100 years.

It is, however, worth to note that although GWP value of CO_2 is relatively lower than other gases, it is still a major concern. This is because it is very abundant and stays in the atmosphere much longer than other types of greenhouse gases (Lindsey, 2020).

Table 4 Examples of Global Warming Potential (GWP) values of greenhouse gases

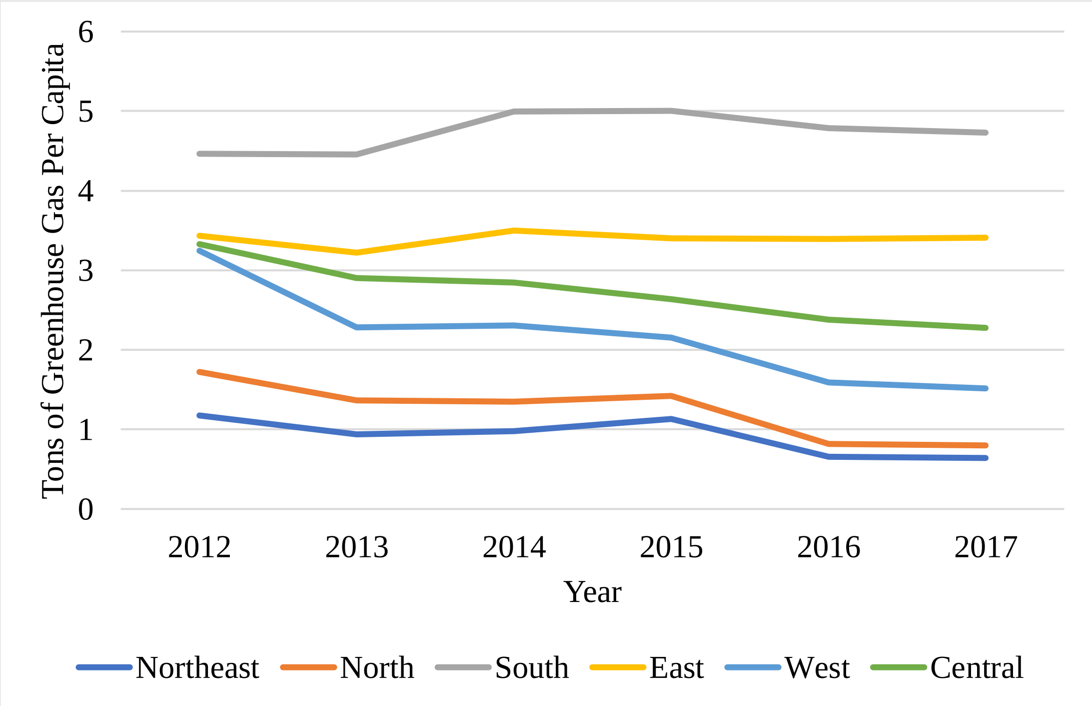
Greenhouse gas	Lifetime (year)	GWP value over 100 years
CO_2	No single lifetime can be given.	1
CH_4	12.4	28
N_2O	121	265
CF_4	50,000	6,630

Source: Intergovernmental Panel on Climate Change (IPCC) (2014)

For overall situation of greenhouse gas emission of Thailand, figure 6 shows the trends of average regional, annual greenhouse gas emission per capita from 2012 to 2017. Southern region had the highest greenhouse emission per capita of more than 4 tons of annual greenhouse gas emission per capita, followed by eastern regions. Figures for both regions are quite consistent over the span of 6 years while other regions show obvious, decreasing trends. Northern and Northeastern regions had the lowest greenhouse gas emission per capita. The values for both regions went below 1 ton in 2016 and 2017.

In accordance with the trends from regional level, 5 out of top 10 provinces with the highest greenhouse gas emission per capita are located in southern region in 2017 as shown in table 5. Phangnga has the highest value, more than 10 tons per capita, in the country. There are also other provinces from different regions: Bangkok in central region; Chon Buri, Rayong, and Trat in eastern region; and Nakhon Sawan in northern region. Meanwhile, 8 out of 10 provinces with the lowest value are in Northeastern region, and the remaining 2 provinces are in northern region as shown in table 6.

Figure 6 Average of greenhouse gas emission per capita in 6 regions from 2012 to 2017



Source: Office of The National Economic and Social Development Council (NESDC) (2021)

Table 5 Top 10 provinces with the highest greenhouse gas emission per capita in 2017

Rank No.	**Provinces**	**Region**	**Greenhouse gas emission per capita (tons of greenhouse gas emission per capita)**
1	Phangnga	South	10.05
2	Surat Thani	South	8.65
3	Krabi	South	7.61
4	Chon Buri	East	7.18
5	Trang	South	6.99
6	Rayong	East	5.52
7	Trat	East	4.97
8	Songkhla	South	4.80
9	Nakhon Sawan	North	4.69
10	Bangkok	Central	3.99

Source: Office of The National Economic and Social Development Council (NESDC) (2021)

Table 6 10 provinces with the lowest greenhouse gas emission per capita in 2017

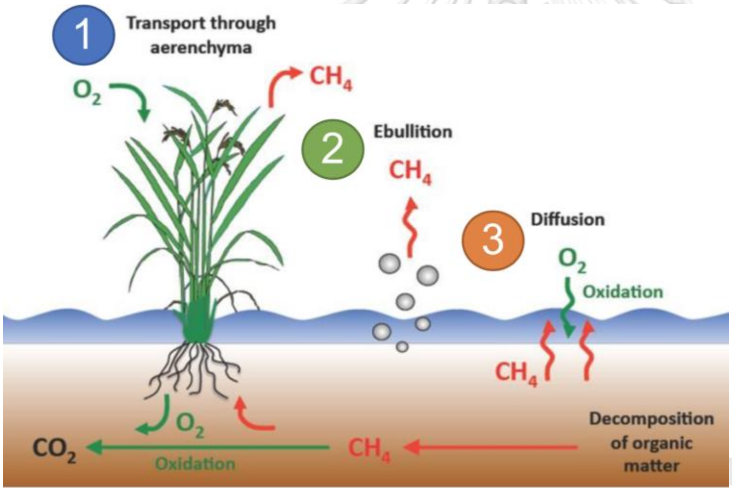
Rank No.	**Provinces**	**Region**	**Greenhouse gas emission per capita (tons of greenhouse gas emission per capita)**
1	Amnat Chareon	Northeast	0.33
2	Mae Hong Son	North	0.33
3	Nongbua Lamphu	Northeast	0.38
4	Kalasin	Northeast	0.44
5	Nakhon Phanom	Northeast	0.46
6	Sakon Nakhon	Northeast	0.48
7	Phayao	North	0.48
8	Surin	Northeast	0.50
9	Chaiyaphum	Northeast	0.50
10	Roi Et	Northeast	0.50

Source: Office of The National Economic and Social Development Council (NESDC) (2021)

2.3 Relationship between Greenhouse Gas Emission and Rice Cultivation

Thailand Greenhouse Gas Management Organization (2018) explained that in flooded rice fields, the anaerobic decomposition of organic material produces CH_4, which escapes to the atmosphere by ebullition through water column, diffusion across the water interface, and transport through the rice plants as shown in figure 7. From 90 to 95 percent of CH_4 emission comes from transportation through aerenchyma while ebullition and diffusion across the water interface are responsible for only 8 and 2 percent, respectively.

Figure 7 Methane emission from rice fields



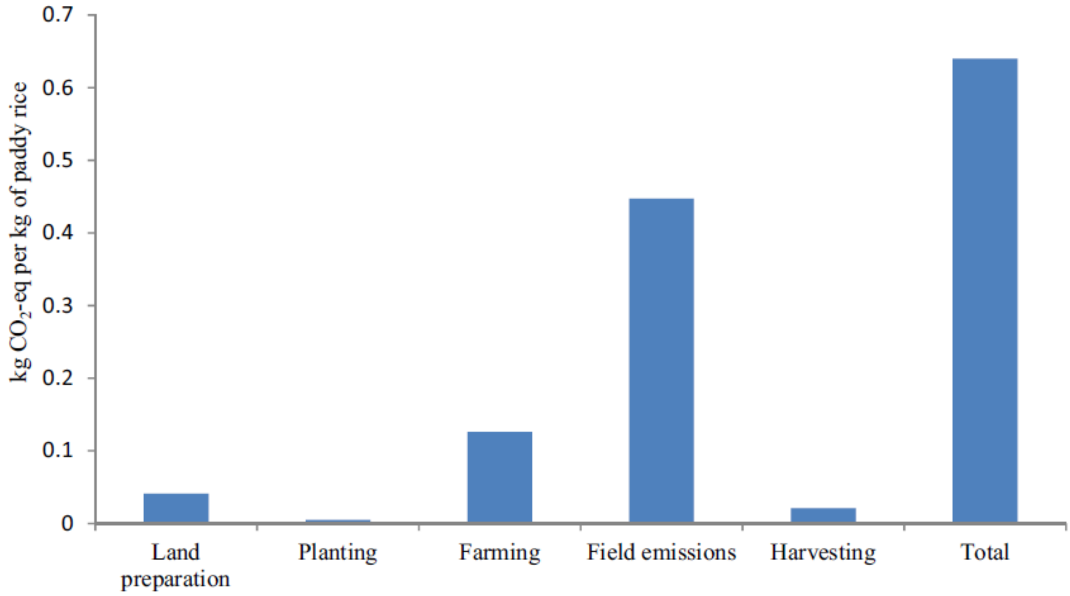
Source: Thailand Greenhouse Gas Management Organization (2018)

Khalil and Aslam (2009) explains that the amount of CH_4 emission depends on 2 major factors which are environmental conditions and agricultural practices. Relevant environmental conditions are soil properties, rain for both amount and timing, wind, and temperature. While there are many agricultural practice factors such as rice cultivar, water management, fertilizer, and crop rotations affecting the emission at different magnitudes, water management and fertilizers are the most significant contributors to the fluctuation of the emission. Water management can be broadly classified into 2 categories, continuous flooding and intermittently flooding. Continuous flooding refers to water management technique in the rice fields that have flooding water kept in the field for most of time in growing season. Meanwhile, intermittently flooding usually involves drainage for at least a week during the mid-season. It is worth to note that another type of water management is rain fed technique which can actually be classified as either continuous flooding or intermittently flooding, depending on location and local climate. For fertilizer, by adding organic amendments to the rice fields can also lead to more CH_4 emission as there are more organic materials to be decomposed.

In addition to CH_4 from rice cultivation, which has already accounted for over half of greenhouse gas emission from agricultural sector in Thailand, the activity also indirectly generates other types of greenhouse gas as well. Jatmiko, Suryani, and Octabriyantiningtyas (2019) mentioned that N_2O and CO_2 are also emitted from rice cultivation. N_2O emission is enhanced by the use of nitrogen fertilizer. An increase in nitrogen concentration in the soil can lead to nitrification and denitrification which then increases the production of N_2O. For CO_2 emission, it occurs from burning fossil fuels when using machines in rice cultivation such as plow, water pumping, and harvesting machines.

Another perspective is to consider the amount of greenhouse emission through life cycle assessment of rice cultivation. Yodkhum, Sampattagul, and Gheewala (2018) conducted an experiment to measure greenhouse gas emission from rice cultivation in northern region of Thailand and divided greenhouse gas emission from rice cultivation into 5 activities: land preparation, planting, farming, field emissions, and harvesting. As shown in figure 8, it is found that about 70% of total greenhouse gas emission comes from field emission, and the major contributor is, again, CH_4 emission. Farming stage, including the use of fertilizers and pesticides, accounts for 20% of the total emission. Similarly, Brodt et al. (2014) conducted an experiment in California, USA, and found that about 69% of the total emission is from field emission followed by farming stage.

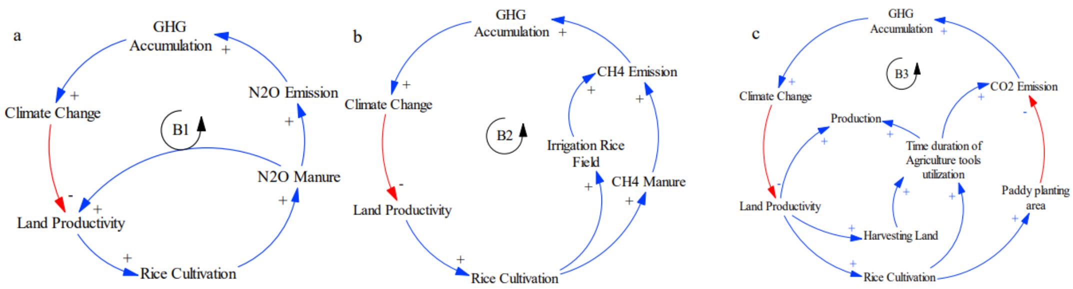
Figure 8 Greenhouse gas emission from rice cultivation in northern region of Thailand



Source: Yodkhum et al. (2018)

It is also worth to mention that casual effect of relationship between rice cultivation and the greenhouse gas emission is bidirectional. In a way, rice cultivation emits greenhouse gas emission both directly and indirectly through related activities. Thus, rice cultivation leads to greenhouse gas emissions. In another way, as greenhouse gases are accumulated over time, they gradually cause climate change phenomenon which, in turn, affects the productivity of rice cultivation. That is, greenhouse gas also affects rice cultivation. Figure 9 (a), (b), and (c) show the casual diagram of rice cultivation with N_2O, CH_4, and CO_2 emission, respectively. The agricultural activities lead to different types of greenhouse gas emissions. However, all are greenhouse gases leading to climate changes which adversely or negatively affect land productivity because of extreme climate change (Jatmiko et al., 2019).

Figure 9 Casual loop diagrams of rice cultivation with N_2O, CH_4, and CO_2 emission



Source: Jatmiko et al. (2019)

2.4 Strategic Plans for Climate Change Mitigation and Adaptation in Agricultural Sector of Thailand

Ministry of Agriculture and Cooperatives (2012) issued the strategic plan for agricultural sector to tackle with the climate change from 2013 to 2016. The plan covers a wide range of improvement in agricultural sector. This includes, for examples, preparing agriculturists for climate change, increasing efficiency in production and competitiveness by voluntarily adopting environmentally friendly farming practices and technology, and developing knowledge base and financial tools.

Overall, the vision of the plan is to "Boosting agricultural immunity as a building block for sustainable development under climate change". Missions of the strategic plan are listed below.

- To promotion farmers' immunity and adaptation to climate change which enhances job security and quality of life with cooperation across stakeholders
- To improve productivity and competency by supporting environmentally friendly production process for goods of food security, alternative energy, and competency in world market
- To research and develop scientific knowledge, technology, and innovation combining with local wisdom to reduce greenhouse gas emission
- To promote knowledge sharing network of cooperation among stakeholders from domestic and foreign organizations to keep update with climate change

situation, technology, trade, investment, and environment for effective production planning and factors of production management to support sustainable growth.

3 main strategies in the strategic plan are shown below.

- Adaptation to Climate Change

  The plan focuses on evaluating vulnerability of agricultural community to climate change and associated risk with job security, enhancing quality of life along with food safety, and introducing technology for adaptation. Climate change can cause more frequent disaster, so efficient communication system is needed to warn farmers for upcoming disasters such as flood. It is also crucial to accurately predict the climate conditions and send out information on time. To collect and utilized useful information from all parties for knowledge and risk assessment, effective information and technology system is essential to be developed and employed such as database for analysis of vulnerability and adaptation.

- Greenhouse Gas Sequestration and Mitigation in Agricultural Sector

  Apart from adaptation to climate change, the sector must also mitigate greenhouse gas emission from the sector. Promoting research about greenhouse gases and their sources are one of the most important strategies. Increasing efficiencies in production can also mitigate greenhouse gas by utilizing fewer natural resources. To further extent, financial tools can possibly induce farmers to mitigate greenhouse gases. For other incentives, the farmers with proper and standardized practice can obtain certified label such as carbon footprint and water footprint to alleviate the non-financial barriers in the world market where the increasing trend of environmental concerns can be observed.

- Driving Strategy for Climate Change in Agricultural Sector

  The main driver mainly comes from fundamental factor such as researches and developments for climate change and informational system. The knowledge development is enhanced across groups of stakeholders such as farmers, researchers, and specialists. Furthermore, human resource under agricultural sector must be trained for improving skills.

Based on budget distribution in table 7, it can be obviously seen that the government has emphasized on adaptation to climate change strategy while greenhouse gas sequestration and mitigation in agricultural sector is the second importance.

Table 7 Budget distribution from 2013 to 2015

Strategy	**Budget (million Baht)**
Adaptation to Climate Change	798.73 (70.31%)
Greenhouse Gas Sequestration and Mitigation in Agricultural Sector	311.16 (27.39%)
Driving Strategy for Climate Change in Agricultural Sector	26.05 (2.29%)
Total	1,135.94 (100%)

Source: Ministry of Agriculture and Cooperatives

CHAPTER III LITERATURE REVIEWS

3.1 Environmental Kuznets Curve (EKC)

Environmental Kuznets Curve, also known as EKC, hypothesis refers to an assumption of an inverted U-shaped curve depicting the relationship between economic development and environmental quality, as shown in figure 10. At the initial stage of economic development, an economic growth is expected to cause a deterioration of environmental quality or an increase in pollution level up to a threshold level of economic development. Beyond that, a further economic development would result in an improvement of environment or a reduction in pollution (David I. Stern, 2004), causing a downward slope in a later stage of economy as shown in figure 10.

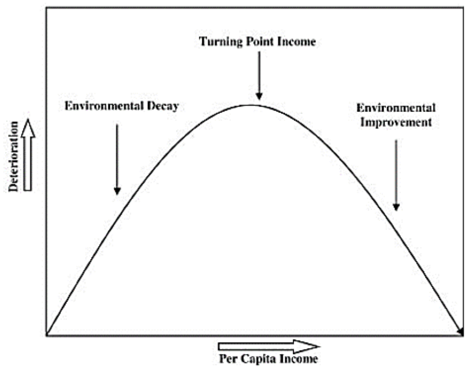
The hypothesis is, therefore, named after Kuznets (1955) as it shares the same inverted-U pattern with Kuznets curve, which explains the relationship between economic development and income inequality (Panayotou, 1993). Nevertheless, Arrow et al. (1995) remark a caution in interpreting the EKC hypothesis that it is developed based on flow concept such as pollution emission rather than stock concept. Therefore, it is possible that when the turning point is reached, environment may be severely damaged such that it would be irreversible. As a result, the hypothesis does not fully guarantee the sustainable development path.

David I. Stern (2004) explained that the earliest EKC hypothesis can be represented by the quadratic regression model. The dependent variable is a pollution per capita, and explanatory variables are gross domestic product (GDP) per capita and squared GDP per capita to capture the inverted-U shape characteristics of the EKC hypothesis. All variables are in natural logarithmic forms. Additionally, intercepts are included in the model to capture country-specific characteristics, and time trend is used to account for time-varying omitted variables. To follow the pattern specified in the hypothesis, the signs for coefficients of GDP per capita and squared GDP per capita are expected to be positive and negative respectively. The turning point or threshold level can then be calculated from the two estimated coefficients.

Meanwhile, Dinda (2004) found that some researchers have extended the polynomial regression from quadratic to cubic form and added other variables influencing environmental degradation or pollution. L. Chen and Chen (2015) concluded that the pattern of the relationship depends on the signs of coefficients in the cubic regression, and there are possible 4 cases.

1. If the coefficients of GDP per capita, squared GDP per capita, and cubed GDP per capita are negative, positive, and zero respectively, then the relationship follows the U pattern.
2. If the coefficients of GDP per capita, squared GDP per capita, and cubed GDP per capita are positive, negative, and zero respectively, then the relationship follows the inverted-U pattern.
3. If the coefficients of GDP per capita, squared GDP per capita, and cubed GDP per capita are negative, positive, and negative respectively, then the relationship follows the inverted-N pattern.
4. If the coefficients of GDP per capita, squared GDP per capita, and cubed GDP per capita are positive, negative, and positive respectively, then the relationship follows the N pattern.

Figure 10 Environmental Kuznets Curve



Source: Yandle, Bhattarai, and Vijayaraghavan (2004)

To explain how economic development can affect environmental quality or pollution level, Grossman and Krueger (1991) identify 3 effects. The first effect is called scale effect. When economy expands, and the number of economic activities increases, the environmental pollution, as a byproduct of production in the industry from the combustion of fossil, will rise consequently, causing environmental quality to deteriorate.

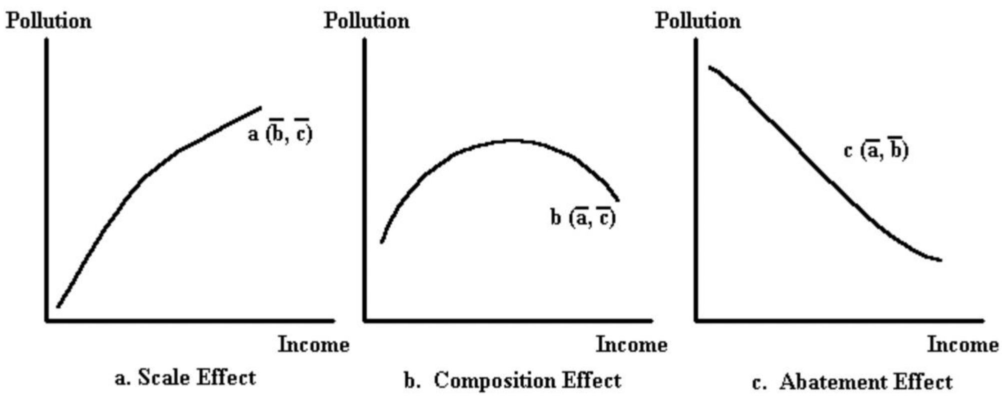
The second effect is composition effect. Based on a comparative advantage, after opening up to the international trade, a country would shift its production toward goods and services which it has a comparative advantage in the international market. The effect of the change on environmental quality depends on the types of goods and services the country shifts to. The environmental quality will get worse if the country produces more goods and services whose byproduct of pollution is high and vice versa.

The last effect is technique effect. It is further decomposed into two components. The first component refers to a positive impact on environmental quality as a result from technological spillover or advanced technology from foreign countries. More advanced or moderner technology is typically more environmentally friendly than older technology. Thus, the environmental quality would improve when a country develops its technology in production. Another component is the demand for a clean environment. For high-income countries, people demand for a cleaner environment associated with their higher wealth and prosperity. Consequently, the governments in these countries would impose stricter environmental policies and regulations to control pollution leading to cleaner environment.

Similarly, Panayotou (1997) describes the relationship between the two variables through 3 effects as shown in figure 11. The first effect is a negative relationship between economic activities and environmental quality as a scale effect. However, composition effect is described in a term of structure of economy at a domestic level rather than at an international level. The compositions of outputs from an economy can be classified by its production sectors. Generally, outputs from industrial sector are more pollution-intensive than from agricultural and service sector. Under economic development phases, an economy usually moves from pre-industrial to industrial stage and from industrial to post-industrial stage, respectively. This, therefore, implies that pollution level would be initially low during pre-industrial stage, as the main composition of output is from agricultural sector. Then, the pollution level will gradually increase as the economy moves toward industrial stage which means more composition of outputs from industrial sector. Finally, it will eventually decline when the economy enters post-industrial stage, and large composition of output is from service sector. For the abatement effect, despite being called by different names, it provides the same explanation as the second component of the technique effect by Grossman and Krueger (1991).

In conclusion, economic development links to the environmental quality in the aspect of pollution level through the three channels which are scale effect, composition effect, and technique or abatement effect. Altogether, the relationship between income and environmental pollution is expected to show a form of inverted-U shape pattern.

Figure 11 Decomposition of income effects on the environment



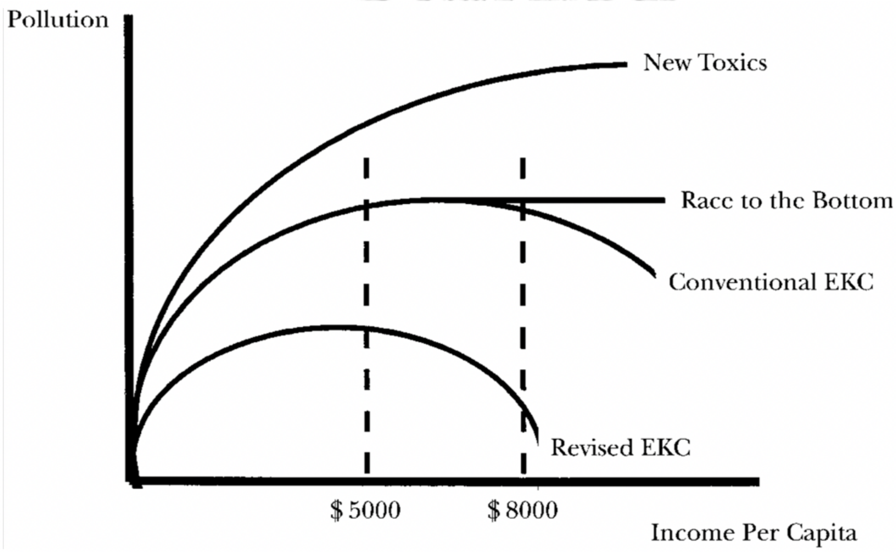
Source: Panayotou (2003)

Likewise, David I. Stern (2002) breaks the EKC hypothesis down into four components, namely scale of production per capita, output mix, input mix, and the state of technology. Scale of production per capita and output mix shares the same explanation as scale and composition effects, respectively, by Panayotou (1997). To further extent, under the scale of production per capita, the pollution emission is assumed to increase proportionally with the production of output, given the same input-output ratio and technology. The next component is input mix or a change in compositions of inputs. The substitution of more environmentally friendly inputs for more harmful inputs can also lead to cleaner environment. For example, replacing coal by natural gas can reduce pollution emission. Given the same amount of output, this is equivalent to a movement along isoquant curves under a neoclassical production function. The last component is the state of technology which is close to the explanation of advanced technology under the technique effect by Grossman and Krueger (1991). David I. Stern (2002), however, emphasizes on the sources of technological improvements. Specifically, some innovations are intentionally developed to reduce environmental impacts while some technological breakthrough indirectly reduce pollution emission. For example, production efficiency and change in process can reduce the required amount of polluting inputs per a unit of output which, in turn, decrease pollution.

Dasgupta, Laplante, Wang, and Wheeler (2002) extended the EKC hypothesis to four different scenarios as shown in figure 12. The first scenario is called "Conventional EKC" which is the standard scenario as explained by Grossman and Krueger (1991). The next two scenarios are the pessimistic views which are "Race to the Bottom" and "New Toxics". "Race to the Bottom" refers to the case that an inverted-U shape relationship or the "Conventional EKC" is just a part of the dynamic process. Eventually, the environmental degradation will continue to rise until the maximum level of pollution is reached. Next, "New Toxics" scenario represents even worse environmental degradation. In the future, the economy will generate new type of pollution which is unregulated. The new pollution will continue to increase and damage the environment. The last scenario shows an optimistic view of the harmonization between the economic growth and the environment, "Revised EKC". It proposes that due to an awareness of the environment quality and advanced technology, it is possible that "Conventional EKC" can shift to the left and the income threshold level will be reduced, causing the environment to improve at an earlier stage of economic development. This depends on the participations and collaboration from various parties such as citizens, policymakers, businesses, and the governments to implement effective environmental policies.

Dasgupta and Wheeler (1997) also found that promoting education can raise the awareness of environmental quality of citizens and therefore indirectly promoting environmental policy implementation. Taguchi (2012) tested SO_2 and CO_2 emission against the scenarios. It was found that among 19 Asian countries, SO_2 emission fits with the "Revised EKC" case while CO_2 emission has a monotonically increasing trend and does not fit with any scenarios even "Race to the Bottom".

Figure 12 Different scenarios of Environmental Kuznets Curve hypothesis



Source: Dasgupta et al. (2002)

3.2 Past Related Researches

The results of past studies on the validity of Environmental Kuznets Curve (EKC) hypothesis on air pollution have been vastly diverse. This could be due to differences in pollution types, research methodologies, time periods, a group of countries, and data sources selected by researchers. The summary of past researches on greenhouse gas emission and CO_2 will be discussed first followed by the researches focusing on agricultural sector. Lastly, other factors affecting the environmental quality are concluded.

3.2.1 EKC Hypothesis and Greenhouse Gas Emission

Overall, the researches for the relationship between greenhouse gas emission and income per capita are inconclusive and vary across countries even if the same research methodology is applied. Table 8 summarizes the results of past related researches on the validity of EKC hypothesis to greenhouse gas emission.

For researches which focus on only one country, El-Aasar and Hanafy (2018) found that EKC hypothesis is invalid to explain the relationship between greenhouse gas emission and income per capita in Egypt for both short run and long run. Instead, the emission and income show a U-shaped relationship in the long run. However, Olale, Ochuodho, Lantz, and El Armali (2018) found the EKC hypothesis for the emission to be valid for Canada from 1990 to 2014. The hypothesis is also confirmed at provincial or territorial level of the country. Likewise, Yang, Lou, Sun, Wang, and Wang (2017) supported the evidence of EKC hypothesis for greenhouse gas emission in Russia. To further extent, under business-as-usual scenario, the turning point for Russia is estimated to be $10,695.75 measured in 2005 U.S. dollars.

For other researches whose focus is on a group of countries, Lapinskienė, Tvaronavičienė, and Vaitkus (2014) tested the relationship between greenhouse gas emission and income per capita among 29 European countries. The results show that the EKC hypothesis is valid for only some countries such as Greece, Spain, Italy, and Portugal while other counties show different patterns of the relationship. For instances, developed countries such as Denmark and Germany have the inverted or negative relationship between the emission and income. Meanwhile, another group of countries including Norway, Ireland, and Switzerland illustrated the N-shaped pattern of the relationship. Similarly, Huang, Lee, and Wu (2008) tested the EKC hypothesis for 21 countries in Annex II under Kyoto Protocol. Only 7 countries, which are Belgium, Canada, Greece, Iceland, Japan, Netherlands, and the U.S., follows the EKC hypothesis. United Kingdom and France shows the negative relationship between Greenhouse gas emission and income per capita, reflecting the classical example that an economic growth can be accompanied by greenhouse gas reduction.

Table 8 Summary of past researches on greenhouse gas emission and validity of EKC hypothesis

Authors	Time Period	Countries/ Cities	Methodology	Does it follow EKC hypothesis?
El-Aasar and Hanafy (2018)	1971-2012	Egypt	ARDL model	No
Olale et al. (2018)	1990-2014	Canada	Fixed Effects Model	Yes
Yang et al. (2017)	1998-2013	Russia	Polynomial regression model	Yes
Lapinskienė et al. (2014)	1995-2008	29 European countries	Polynomial regression model	The results vary across countries.
Huang et al. (2008)	1990-2003	21 countries listed in Annex II under Kyoto Protocol	Polynomial regression model	The results vary across countries.

3.2.2 EKC Hypothesis and CO_2 Emission

Table 9 summarizes the results of past related researches on the validity of EKC hypothesis to CO_2 emission. Although focusing on the same environmental pollution, the results are still inconclusive.

Applying different econometric methodologies to panel datasets across countries and years, Saraç and Yağlikara (2017); Chow and Li (2014); Apergis and Ozturk (2015); and Jafari, Farhadi, Zimmermann, and Yahoo (2017) found the evidence to support the existence of EKC hypothesis across countries. To further extent, the turning points or the threshold levels of the emission are, however, found to be varied for different groups of countries. Jafari et al. (2017) applied Generalized

Method of Moments (GMM) and classified countries into 3 groups which are developed economics; developing economics and economics in transition; and less developed economics. Less developed economics has the lowest turning point of $1,147. Developing economics and economics in transition has the turning point of $5,783. For developed economics, even though the EKC hypothesis is valid when all economics are included in the model, it is found that developed economics show the pattern of N-shaped relationship between income per capita and CO_2 emission. The first turning point is $11,649, and the second is $30,393. Both points are much higher than other two economic groups. Saraç and Yağlikara (2017) relatively narrowed down the focused group of countries and have found the turning point of $7,990 for Black Sea Economic Cooperation or BSEC countries by applying Fixed Effects Model. Therefore, the turning point is highly subject to econometrics methodologies and a focused group of countries.

Meanwhile, Adu and Denkyirah (2017) and Taguchi (2012) proved that EKC hypothesis is invalid to explain the relationship between economic development and environmental quality among African and Asian countries, respectively. Taguchi (2012) has argued that greenhouse gases emission regulatory is set domestically and internationally only after Kyoto Protocol in 1997, and Asian countries, excluding Japan, do not have legal obligation in the protocol to reduce the emission, so the countries are lack of motivation to set the strict emission-control policies, and this is also due to technological advancement of the countries. Similarly, Shafik and Bandyopadhyay (1992) explains about the invalidity of EKC hypothesis for CO_2 emission as a free rider problem. Since there is not any major local or domestic cost associated with CO_2 emission. Rather, the effect of CO_2 emission which is a climate change is at a global level. Therefore, many countries lack of motivation to strictly regulate the emission. Additionally, CO_2 emission is found to be in a monotonically rising trend.

David I. Stern, Common, and Barbier (1996) argued that the regression models which covers datasets across countries could suffer from some problems such as heteroskedasticity and suggested the research results would be more beneficial if the historical experiences of the individual countries are examined at a time. Some studies attempted to identify the existence of EKC for a single country. Jalil and Mahmud (2009) and Saboori, Sulaiman, and Mohd (2012) applied an autoregressive distributed lag (ARDL) model to time-series datasets and found that the relationship between the economic growth and environmental pollution illustrates an inverted-U shape pattern for China and Malaysia, respectively. Although Baek (2015) applied the same model, EKC hypothesis is proven to be valid in only Iceland among 7 Arctic countries, excluding Russia.

In addition to the pattern of the relationship between economic growth and pollution, the EKC hypothesis also implies the unidirectional causality running from economic growth to the pollution. Thus, some researchers have attempted to verify the directions of this causality, but the empirical results are still mixed and inconclusive. Jalil and Mahmud (2009) applied Pair wise Granger Causality Test and found a unidirectional causality running from economic growth to CO_2 emission in China. However, Ang (2008) found the opposite result for Malaysia by applying Granger Causality test based on Vector Error-Correction Model (VECM). the weak, unidirectional causality is found to run from the pollution emission to economic expansion. That is, the pollution stimulates more economic growth. Meanwhile, Halicioglu (2009) found bilateral causality between the two variables in Turkey. Coondoo and Dinda (2002) summarized the fact that the direction and nature of causality vary from one country to another.

Table 9 Summary of past researches on carbon dioxide emission and validity of EKC hypothesis

Authors	Time Period	Countries/ Cities	Methodology	Does it follow EKC hypothesis?
Shafik and Bandyopadhyay (1992)	1960-1989	118-153 countries	Fixed Effects Model	No
Saraç and Yağlikara (2017)	1992-2011	11 BSEC countries	Fixed Effects Model	Yes
Adu and Denkyirah (2017)	1970-2013	7 West African countries	Random Effects Model	No
Taguchi (2012)	1950-2009	19 Asian countries	Generalized Method of Moments (GMM)	No
Jalil and Mahmud (2009)	1975-2005	China	ARDL Model	Yes
Baek (2015)	1960-2010	7 Arctic Countries excluding Russia	ARDL Model	-Yes for Iceland only -No for the others
Chow and Li (2014)	1992-2004	132 countries	t-test statistic	Yes
Saboori et al. (2012)	1980-2009	Malaysia	ARDL Model	Yes
L. Chen and Chen (2015)	1985-2010	31 provincial regions	Simple Additive Model (Nonparametric Approach)	Yes
Apergis and Ozturk (2015)	1990-2011	14 Asian countries	Generalized Method of Moments (GMM)	Yes
Jafari et al. (2017)	1980-2009	166 countries	Generalized Method of Moments (GMM)	Yes

3.2.3 EKC Hypothesis in Agricultural Sector

Even though the EKC hypothesis has been verified for the relationship between GDP per capita and environmental quality, only a few literatures specifically focus on agricultural sector. Furthermore, the results are still inconclusive.

Zafeiriou et al. (2017) has verified the EKC hypothesis for Bulgaria, Hungary, and Czech Republic in both short run and long run. It is found that in long run, Bulgaria and Czech Republic follows the EKC while the EKC hypothesis is only validated for Bulgaria. The results indicate that farming practices and crops' selection does not secure the growth in economic and environmental quality simultaneously at least in short run and also in long run for Hungary. The modification in environmental policies is needed.

Moutinho, Madaleno, and Elheddad (2020) verified the EKC hypothesis for 7 economic sectors for OPEC countries. It is found that gross value added from agricultural sector and CO_2 emission per capita follows U-shaped relationship.

3.2.4 Other Factors Affecting Air Pollution

Apart from the economic growth which is usually determined by income per capita, there are many other factors affecting the air pollution. Table 10 summarizes these factors from past researches.

3.2.4.1 Energy Consumption

Saraç and Yağlikara (2017); Jalil and Mahmud (2009); and Baek (2015) have all found a statistically significant positive relationship between energy consumption and CO_2 emission. Higher energy consumption would lead to higher emission. This aligns with the explanation from Intergovernmental Panel on Climate Change (IPCC) (2014). that fossil fuel combustion, considered as one of energy consumption, is a major cause of anthropogenic CO_2 emission.

To further extent, Özbuğday and Erbas (2015) found a positive significant effect of energy efficiency on CO_2 emissions in the long-run, and substituting renewable energy for non-renewable energy can reduce the emission.

3.2.4.2 Population Density

The relationship between the population density and economic growth is inconclusive. Managi and Jena (2008) tested the relationship between income per capita and aggregated air pollution indicators of SO_2, NO_2, and SPM in India and found the negative relationship which means more densely populated cities would have worsened environmental quality than less densely populated cities. Similarly, Grossman and Krueger (1991) found higher concentration of SO_2 and dark matter in more densely populated density for countries around the world.

On the contrary, Apergis and Ozturk (2015) found that higher population density can improve CO_2 emission among 14 Asian countries. It is explained that even though demanded for more energy consumption derived from fossil combustion is higher in a densely populated area, people living in the area also raise more concerns and higher demand for strict pollution control policies. Thus, it is possible for the relationship between environmental quality and population density to be either positive or negative. Panayotou (1997) gives the same explanation about the ambiguous signs of the population density for SO_2 concentration and found that the signs change as sets of explanatory variables change. Nevertheless, Adu and Denkyirah (2017) did not found any statistically significant relationship between the population density and CO_2 emission among 7 West African countries.

3.2.4.3 Urbanization

Empirical evidence indicates the negative relationship between urbanization and the environment but for some countries only. Jafari et al. (2017) who applied to Generalized Method of Moments (GMM) to find the existence of the EKC hypothesis for 166 countries found an expansion of urbanization would increase CO_2 emission among least developed countries only. This is due to the failure of the governments and institutions to maintain the environmental standards during the expansion process.

Managi and Jena (2008) found the same type of relationship for aggregated air pollution indicators in India.

3.2.4.4 Trade Openness

Empirical evidences of the relationship between trade openness and the environmental quality are still controversial even though the hypothesis has been clearly stated. Grossman and Krueger (1991) who assessed the impact of North American Free Trade Agreement on the environment applied the concept of comparative advantage to hypothesize the relationship between international trade and the environment. If the international trade is liberalized, then a country will shift its production to a good or service that intensively uses its abundant factors. Thus, the relationship between the trade liberalization and the environment will be uncertain, depending on if a country shifts its production to more or less polluted-intensive goods and services. However, if the competitive advantage for the international trade heavily depends on environmental regulation implemented by the government, trade liberalization will worsen the environment as producers will shift their production to less regulated production sector to gain the competitive advantage in the international market. It is found that countries with higher degree of trade openness will have lower SO_2 concentration for sampled countries around the world.

Similar to the second hypothesis from Grossman and Krueger (1991), Antweiler, Copeland, and Taylor (2001) investigated the relationship between pollution concentration and trade openness under pollution haven hypothesis. The hypothesis refers to the scenario when the comparative advantage comes from less strict environmental regulations. Consequently, multinational firms would relocate their productions to countries which have less strict regulations and those are likely to be relatively low-income countries. Thus, high-income countries which have strict environmental regulations will be free of highly-polluted industries, and they are relocated to low-income countries. It is, however, found that, in all, free trade appears to be good for the environment.

Later, Adu and Denkyirah (2017) has found a positive relationship between trade openness and CO_2 emission for African countries as these countries export more of polluted goods rather than importing energy-efficient technologies which enables local producers to produce less-polluted goods. Additionally, it is also found that a currency depreciation would lead to an increase in CO_2 emission. As the depreciation indicates a weak economy, so this is a sign to increase economic activities for investors which, in turn, increase CO_2 emission. Jalil and Mahmud (2009) and Jafari et al. (2017), however, did not found any significant relationship between trade openness or liberalization and the environment degradation.

3.2.4.5 Industry Share of GDP

The effect of industrial share is still inconclusive. Both Panayotou (1997) and Apergis and Ozturk (2015) found a non-decreasing, significant relationship between the share of industry sector to GDP and air pollution, which are SO_2 concentration and CO_2 emission, respectively. To further extent, Panayotou (1997) uses this factor to represent the composition effect. An industrial sector requires high energy consumption in production which worsens environmental quality.

However, Özbuğday and Erbas (2015) found the significances of its impacts on CO_2 emission vary from one country to another. While for some countries such as Australia, Brazil, and Canada, an increase in the industrial share can lead to higher emission, a rise in industrial share can also lead to lower emission in other countries such as Norway, South Africa, and Turkey. Additionally, many other countries such as Chile, France, and Ireland do not have a significant relationship between industrial share and the emission.

3.2.4.6 Time Trend

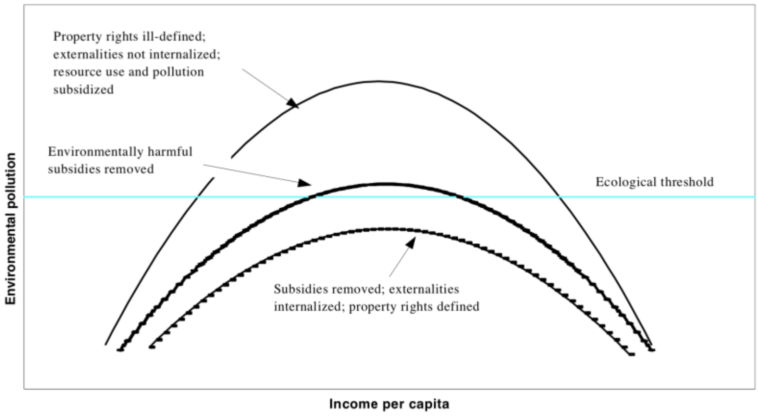
Grossman and Krueger (1991) included a time trend in the model to allow for a change in pollution level and pollution abatement caused by environmental awareness worldwide. Similarly, Apergis and Ozturk (2015) uses a time trend to represent technological advancement, same as the study of Panayotou (1997), and environmental awareness.

3.2.4.7 Quality of Institutions and Regulations

In order to study the relationship between SO_2 concentration and income per capita, Panayotou (1997) includes a policy variable to capture the quality of institutions who are responsible for designing and implementing environmental policies. The result shows that a better quality of institutions can decrease the pollution concentration. In figure 13, it is shown that an improvement in environmental policies and environment-related institutions can flatten the curve of income-environment relationship. Therefore, the turning point can be achieved before reaching the ecological threshold which determines the reversibility of environmental damages. Such effective, environmental policies should internalize externalities, reducing environmentally harmful subsidies, or enforcement of property rights over natural resources.

Similarly, among Asian countries, Apergis and Ozturk (2015) found that better quality of regulations to formulate and implement more effective policies can decrease CO_2 emission. In addition, the government effectiveness reflecting quality of public services and credibility of the government's commitment to its policies can also improve the environment or lower the pollution emission.

Figure 13 The income-environment relationship under different policies and institutional scenarios



Source: Panayotou (1997)

3.2.4.8 Other Variables

There are other variables which only few researches have applied but found significant relationship with the environment. For example, Jafari et al. (2017) found that the proportion of the government expenditure to GDP is statistically significant to the CO_2 emission for developed countries. Because the governments in these developed countries is efficient to harmonize the conflict between private and social interest, they successfully internalize the negative externality to the environment and clear market failure. Managi and Jena (2008) also found that an improvement in education can lead to a better environmental quality through an awareness of the importance of the environment. However, the magnitude is quite small.

Table 10 Summary of past researches on other factors affecting air pollution

Authors / Variables	Saraç and Yağlikara (2017)	Jalil and Mahmud (2009)	Baek (2015)	Managi and Jena (2008)	Grossman and Krueger (1991)	Apergis and Ozturk (2015)	Adu and Denkyirah (2017)	Jafari et al. (2017)	Panayotou (1997)	Özbuğday and Erbas (2015)
Energy Consumption	✓	✓	✓					✓		
Energy Efficiency										✓
Population Density				✓	✓	✓	✓		✓	
Urbanization				✓				✓		
Trade Openness		✓			✓		✓	✓		
Industry Share of GDP						✓			✓	✓
Time Trend					✓	✓			✓	
Quality of institutions and regulations						✓			✓	
Government Expenditure Share of GDP								✓		
Education				✓						
FDI share of GDP								✓		

Official Exchange Rate							✓			
Land Area						✓				
Political System					✓					
City Location					✓					
Land Use					✓					
Location within the city					✓					

CHAPTER IV RESEARCH METHODOLOGY

This study applies panel regression analysis and systematic review as research methodologies. Firstly, panel regression analysis is applied to examine the relationship between greenhouse gas emission per capita and income from rice production of Thailand to achieve the first research objective. Systematic review is applied as a tool to achieve the second research objective which is to study about greenhouse gas mitigation practices in rice production while benefitting businesses.

4.1 Panel Regression Analysis

4.1.1 Data Sources and Variables

Greenhouse gas emission per capita, the real value of GPP (Gross Provincial Product) from rice production, and the share of industrial sector to GPP used in panel regression analysis are secondary data sourced from the Office of the National Economic and Social Development Council (NESDC), Thailand. Population Density is sourced from National Statistical Office of Thailand (NSO), and final commercial energy consumption from oil is sourced from Energy Policy and Planning Office (EPPO), Ministry of Energy, Thailand. Average area of rice field per household, proportion of fertilized rice field to total area of rice field, and number of rice farmers' households are sourced from Office of Agricultural Economics of Thailand. The panel data is an annual dataset from 2012 to 2017 at a provincial level. Variables and description are listed in table 11.

Table 11 Variables and Description

Variable	Description	Unit
GHG	Greenhouse gas emission per capita	Tons of greenhouse gas emission per capita
RGPP	The real value of GPP (Gross Provincial Product) from rice production calculated by Chain Volume Measures (CVM)	Million Baht (2002 as a reference year)
INDUSTRIAL	The proportion of industrial production value to total GPP	Percentage (%)
POPDENSITY	Population Density	Number of persons per squared kilometers
ENERGY	Final commercial energy consumption from oil per capita	Tons of oil equivalent per capita
TIME	Time trend	Year
RLAND	Average area of rice field per household	Hectare per household
FERTILIZER	Proportion of fertilized rice field to total area of rice field	Percentage (%)
RHH	Number of rice farmers' households	Household

4.1.2 Methodology

This study examines the relationship between the real rice production value and greenhouse gas emission per capita. Hence, the panel regression analysis is applied with procedure as shown in figure 14. The procedure is applied to 4 scenarios differed by applied datasets. Those 4 scenarios are:

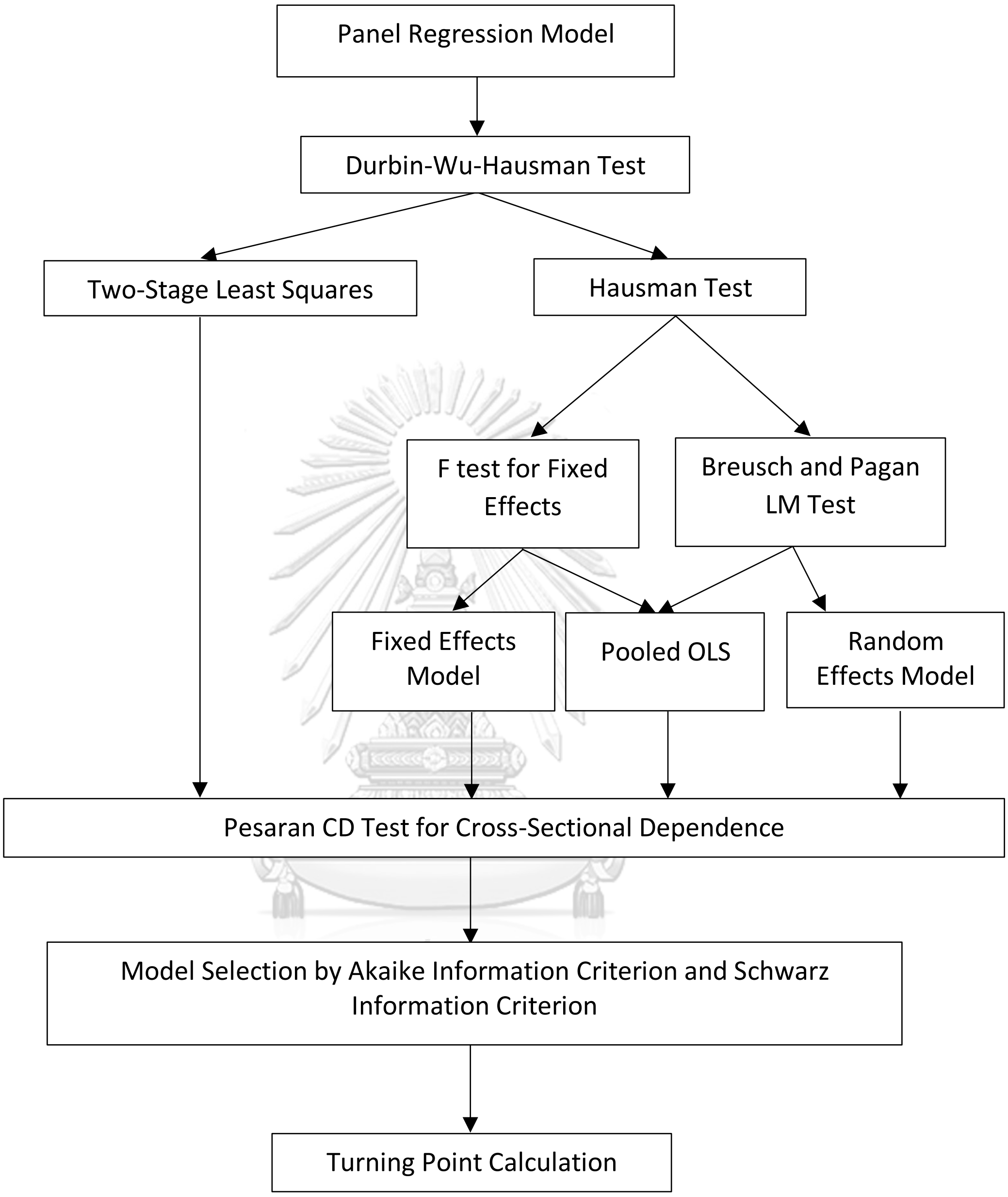
- The polynomial regression model with data from all provinces in Thailand
- The polynomial regression model with data from only provinces with the real rice production value of more than 10 million baht on average over the year of 2012 to 2017

- The polynomial regression model with data from 22 provinces located in Chao Phraya Basin area (Royal Irrigation Department of Thailand, 2020)

As the dataset including all 77 provinces has wide range of real rice production value, it is, therefore, worth to investigate the shape of relationship for provinces whose production value is not relatively too low. Hence, the analysis is also applied to the dataset which contains only provinces with the real rice production value of more than 10 million baht on average over the year of 2012 to 2017. Additionally, the relationship is also examined among the provinces with high proportion of irrigated rice fields, which are the provinces in Chao Phraya Basin area.

From the procedure, the endogeneity problem arisen from potential simultaneity bias is investigated first. Then, various statistical tests are applied to select the most appropriate models: Two-Stage Least Squares (TSLS), Fixed Effects Model (FEM), Random Effects Model (REM), and Pooled OLS. Next, Pesaran CD Test for Cross-Sectional Dependence is applied to test for autocorrelation. If the test indicates the problem, White's robust standard error is applied. Akaike Information Criterion and Schwarz Information Criterion are applied to compare between squared and cubic polynomial regression models. Lastly, turning point from the models is calculated.

Figure 14 Procedure for Panel Regression Analysis



4.1.2.1 Panel Regression Model

This study follows both squared and cubic polynomial regression forms to test for the validity of EKC hypothesis and adds other control variables in the model. However, instead of using income per capita as an independent variable, the model in this study uses the value of rice production. Since Jatmiko et al. (2019) shows bidirectional relationship between rice production and greenhouse gas emission, this study takes this into account. The structural equations model in this study can be written as:

$$\mathrm{lnGHG}_{it} = \beta_0 + \beta_1 \mathrm{lnRGPP}_{it} + \beta_2 (\mathrm{lnRGPP})^2_{it} + \beta_3 (\mathrm{lnRGPP})^3_{it} + \beta_4 \mathrm{lnINDUSTRIAL}_{it} + \beta_5 \mathrm{lnPOPDENSITY}_{it} + \beta_6 \mathrm{lnENERGY}_{it} + \beta_7 \mathrm{TIME} + \varepsilon_{it} \quad (1)$$

$$\mathrm{lnRGPP}_{it} = \alpha_0 + \alpha_1 \mathrm{lnGHG}_{it} + \alpha_2 \mathrm{lnRLAND}_{it} + \alpha_3 \mathrm{lnFERTILIZER}_{it} + \alpha_4 \mathrm{lnRHH}_{it} + \alpha_5 \mathrm{TIME} + \varepsilon_{it} \quad (2)$$

Where i denotes province where i=1, 2, 3, …, 77, and t denotes year where t=1, 2, 3, …, 6. All variables, except TIME, are in natural logarithmic forms. The pattern of the relationship between the rice production value and greenhouse gas emission per capita depends on the signs of β_1, β_2, and β_3. If the EKC hypothesis is valid to explain the relationship between the variables, then $\beta_1>0$, $\beta_2<0$, and $\beta_3=0$ in cubic polynomial or $\beta_1>0$ and $\beta_2<0$ in squared polynomial.

From literature review in chapter 3, The expected signs for explanatory variables in equation (1) are summarized in table 12.

Table 12 Expected signs

Variables	**Expected Sign**	**Description**
RGPP	+	According to Environmental Kuznets Curve Hypothesis, the expected sign of the variable is positive to show the inverted-U shape relationship with the pollution emission.
$(RGPP)^2$	-	According to Environmental Kuznets Curve Hypothesis, the expected sign of the variable is negative to show the inverted-U shape relationship with the pollution emission.
$(RGPP)^3$	+	The inverted-U shape relationship can be a temporary phenomenon, so the relationship can take the second turn. A further growth in rice production can lead to an increase in greenhouse gas emission due to a difficulty in keeping technological improvement up with a continuing growth of rice production.
INDUSTRIAL	+	Industrial sector consumes large amount of energy which originates from fossil combustion process. Thus, more pollution emission is expected from an economy with relatively larger industrial sector.
POPDENSITY	+	More densely populated city is expected to consume more energy and, therefore, generates more greenhouse gas emission.
ENERGY	+	More consumed energy from oil indicates more fossil combustion which, in turn, emits more greenhouse gas emission.
TIME	-	Time is used as a proxy for technological advancement. As more environmentally friendly technology is developing over time, greenhouse gas emission is expected to decrease.

4.1.2.2 Durbin-Wu-Hausman Test

If lnGHG and lnRGPP show bidirectional relationship, then estimators in equation (1) and (2) estimated by Ordinary Least Squares (OLS) will be biased or not consistent, even if the sample size increases indefinitely. This is due to simultaneity bias which causes the problem of endogeneity.

The problem of endogeneity occurs when one or more regressor(s) is correlated with the error term. This could be due to various issues such as omitted variable and simultaneity bias. As a result, the OLS estimators are biased because it violates one of the assumptions of Classical Linear Regression Model (CLRM) held for OLS to yield Best Linear Unbiased Estimator (BLUE). The violated assumption specifies that the expected value of the error terms given values of regressors, is zero, implying no correlation between error term and regressors. A regressor correlated with the error term is called endogenous variable as its value is determined within the model. A regressor which is not correlated with the error term is called exogenous or predetermined variable. In equation (1) and (2), GHG and RGPP are endogenous variables as their values are determined within the model. Meanwhile, INDUSTRIAL, POPDENSITY, ENERGY, TIME, RLAND, FERTILIZER, and RHH are exogenous variables.

For simultaneity bias, generally, in term of cause and effect in the regression model, regressor, X, cause regressand, Y, or the direction of effect is from X to Y. However, under some condition, Y can also have effect on X at the same time. This is called simultaneity bias which will cause the OLS estimator to be inconsistent. Since their values are determined within the model, they are also endogenous variables.

Simultaneity and endogeneity bias can be handled by estimating the simultaneous equations model with Two-Stage Least Squares (TSLS) method whose concept is based on instrumental variable.

Instrumental variable or instrument refers to a variable which can be used as a proxy for an endogenous variable in the structural equation model. It does not directly affect the dependent variable. Rather, its effect passes through the independent variable. There are main criteria to be considered for an instrumental variable. Firstly, the instrumental variable must be correlated with the endogenous variable that it is intended to be used as proxy. Regardless of the direction of relationship, positive or negative, the stronger correlation of the two variables, the better instrument. Secondly, the instrumental variable must not be correlated with the error term in the model. To further extent, number of instruments must be at least equal to the number of endogenous variables in the model.

In this study, lnENERGY variable is used as an instrument for lnGHG and lnRLAND variable is used as an instrument for lnRGPP.

Table 13 Correlation coefficients between endogenous variables and instrumental variables

Variable	lnGHG	lnRGPP	lnENERGY	lnRLAND
lnGHG	1			
lnRGPP	-0.54	1		
lnENERGY	0.62	-0.23	1	
lnRLAND	0.06	0.54	0.30	1

Regardless of positive or negative sign, greater value of correlation coefficient means stronger relationship between variables. From table 13, the correlation coefficient of lnGHG and lnENERGY is 0.62, which is higher than the value of lnRGPP and lnENERGY, -0.23, so lnENERGY can be an instrumental variable for lnGHG. Similarly, the value of lnRGPP and lnRLAND is 0.54, which is higher than the value of lnGHG and lnRLAND, 0.06, so lnRLAND can be an instrumental variable for lnRGPP.

After the instrumental variables have been identified, they are then applied in TSLS. The method involves 2 main steps. First, both endogenous variables will be regressed on all exogenous variables, including instrumental variables, in equation (3) and (4). Secondly, the values of $\ln R\widehat{G}PP_{it}$ and $\ln G\widehat{H}G_{it}$ from equation (3) and (4) are instrumented in equation (1) and (2) for $\ln RGPP_{it}$ and $\ln GHG_{it}$, respectively.

$$\ln R\widehat{G}PP_{it} = \gamma_0 + \gamma_1 \ln RLAND_{it} + \gamma_2 \ln FERTILIZER_{it} + \gamma_3 \ln RHH_{it} + \gamma_4 \ln INDUSTRIAL_{it} + \gamma_5 \ln POPDENSITY_{it} + \gamma_6 \ln ENERGY_{it} + \gamma_7 TIME + \varepsilon_{it} \quad (3)$$

$$\ln G\widehat{H}G_{it} = \delta_0 + \delta_1 \ln RLAND_{it} + \delta_2 \ln FERTILIZER_{it} + \delta_3 \ln RHH_{it} + \delta_4 \ln INDUSTRIAL_{it} + \delta_5 \ln POPDENSITY_{it} + \delta_6 \ln ENERGY_{it} + \delta_7 TIME + \varepsilon_{it} \quad (4)$$

In this study, Durbin-Wu-Hausman Test is applied to determine if lnRGPP is endogenous. The hypothesis can be written as:

H_0: lnRGPP is exogenous.

H_a: lnRGPP is endogenous.

Its null hypothesis states that the variable of interest, lnRGPP, is exogenous. If the null hypothesis is rejected, then TSLS is applied. Otherwise, OLS can be applied without endogeneity bias.

4.1.2.3 Hausman Test

If there is not an endogeneity problem in this study, Hausman Test is applied to compare between Fixed Effects Model (FEM) and Random Effects Model (REM) estimated by OLS. Whether to select REM or FEM depends on the correlation between the regressors and cross-section specific error component. If it assumes that the error component and regressors are uncorrelated, then REM is appropriate to estimate the model. The mathematical expression can be written as:

$$E[X_{it}\varepsilon_i] \neq 0$$

However, if they are correlated, then FEM is appropriate. Hausman Test can be written as below. If the null hypothesis is rejected at given significant level, then fixed effects model is selected. Otherwise, random effects model is used.

H_0: Random Effects Model is appropriate.

H_a: Fixed Effects Model is appropriate.

4.1.2.4 F Test for Fixed Effects

If Hausman Test indicates that fixed effects model is more appropriate than random effects model, then the next step is to compare fixed effects model to pooled regression model by F-statistics which is to test the joint statistical significance of fixed effects, capturing individual-specific factor, in the fixed effects model. The hypothesis can be written as:

H_0: Pooled Regression Model is appropriate.

H_a: Fixed Effects Model is appropriate.

If the null hypothesis is rejected at a given significant level, the fixed effects are statistically significant, and the model is the most appropriate for the estimation.

On the contrary, if the null hypothesis is failed to be rejected, the dummy variables are statistically insignificant, and pooled regression model should be selected instead.

4.1.2.5 Breusch and Pagan LM Test for Random Effects Model

If, from Hausman test, random effects model is selected, then Breusch and Pagan LM test is applied to compare between random effects model and pooled regression model. The test focuses on if the variance across observations is zero. If the variance is not equal to zero, then random effects model is more appropriate than pooled regression model. The hypothesis of Breusch and Pagan LM test can be written as:

H_0: Pooled Regression Model is appropriate.

H_a: Random Effects Model is appropriate.

If the null hypothesis is rejected at a given significant level, the variance is not equal to zero, and the random effects model is the most appropriate. On the contrary, if the null hypothesis is failed to be rejected, the variance is equal to zero, and pooled regression model should be selected instead.

4.1.2.6 Autocorrelation

The selected model is then diagnosed for autocorrelation by Pesaran CD Test for Cross-Sectional Dependence. Autocorrelation refers to the problem that the error term is correlated with another lagged error term. The mathematical expression can be written as:

$E[\varepsilon_i\varepsilon_j] = 0$

In the presence of autocorrelation, the OLS method still yields unbiased and consistent estimators but they are not efficient. Because of autocorrelation, OLS standard errors are underestimated, and, as a result, the values of t statistics are inflated, misleading about the significance of coefficients. In all, the values of both t and F statistics are invalid.

Pesaran CD test is applied to detect autocorrelation. The hypothesis set can be written as:

H0: $E[\varepsilon_i\varepsilon_j] = 0$ (No autocorrelation)

Ha: $E[\varepsilon_i\varepsilon_j] \neq 0$ (There is autocorrelation.)

If null hypothesis is rejected at a given significant level, then there is an evidence of autocorrelation. On the contrary, if the null hypothesis is failed to be rejected, then there is no evidence of autocorrelation.

4.1.2.7 Model Selection

From the literature review, it can be observed that the EKC hypothesis can be initially presented as squared polynomial regression model. However, some studies extend it to test against cubic polynomial form. Likewise, this study also tests the models against both squared and cubic polynomials. Apart from statistical significance of cubic term, Akaike Information Criterion (AIC) and Schwarz Information Criterion (SIC) are applied as additional criteria to select the most appropriate model. The two criteria can be calculated by:

$$AIC = e^{2k/n}\frac{RSS}{n} \text{ and } SIC = n^{k/n}\frac{RSS}{n}$$

Where k is a number of regressors including intercepts, n is number of observations, and RSS is residual sum of squares.

For both criteria, they impose the penalty to a model as more regressor is added. A model with lower values of AIC and SIC is preferred. From the formulas, SIC imposes harsher penalty than AIC.

4.1.2.8 Turning Point Calculation

After the appropriate model has been selected. If a cubic equation is selected, the first and second turning points can be calculated with the following formulas (Diao, Zeng, Tam, & Tam, 2009) with a modification of an exponential function to reverse the effect of the natural log:

$$X_1 = e^{\frac{-\beta_2-\sqrt{\beta_2^2-3\beta_1\beta_3}}{3\beta_3}} \text{ and } X_2 = e^{\frac{-\beta_2+\sqrt{\beta_2^2-3\beta_1\beta_3}}{3\beta_3}}$$

Where X_1 and X_2 represent the first and second turning points. β_1, β_2, and β_3 are coefficients of lnRGPP, $(\text{lnRGPP})^2$, and $(\text{lnRGPP})^3$ respectively.

If a squared equation is selected, then the turning point can be calculated with the following formula (David I. Stern, 2004):

$$X^* = e^{\frac{-\beta_1}{2\beta_2}}$$

Where X* is the turning point. β_1 and β_2 are coefficients of lnRGPP and $(\text{lnRGPP})^2$ respectively.

4.2 Systematic Review

In order to answer the second research objective which is to study greenhouse gas mitigation practices in rice cultivation while benefitting farm incomes, systematic review is applied as a research tool. Previous studies including evaluation of impact of rice farming practices on greenhouse gas emissions and economic benefit are selected into this study.

To scope down and create the search strategy, this study has opted to apply an indicator called Net Ecosystem Economic Benefit, abbreviated as NEEB, as one of the main search terms. The indicator is suitable to answer the research objective because it takes both economic benefits and impact of agricultural practices on greenhouse gas emission into account. Z. S. Zhang, Guo, Liu, Li, and Cao (2015) explained the indicator can be calculated as follows:

NEEB = Yield Gain – Agricultural activity costs – GWP cost

Yield gain is a revenue calculated by current crop price multiplied by crop yield. It can be written in mathematical expression as:

Yield Gain = crop price*crop yield

Next, agricultural activity costs include various expenses such as mechanical tillage, fertilizers, crop seeds, pesticides, mechanical harvesting, etc. GWP cost enables the indicator to take impact of agricultural practices into account. In other words, the term is used to internalize the negative externality of rice farming practice on the climate change contribution. The cost is calculated on the basis of carbon-trade prices and the value of GWP. GWP is the sum of multiplications of total CH_4 and N_2O emissions with their respective radiative forcing potential. It can be written as:

GWP = (total amount CH_4 emission*Radiative Forcing Potential of CH_4) + (total amount N_2O emission*Radiative Forcing Potential of N_2O)

From the equations above, it can be seen that the indicator captures the effects of agricultural practices in multiple ways. First, the practices can impact crop yield which has been included in yield gain. Next, as the practices possibly incur additional cost, this would be included in agricultural activity cost. Lastly, the impact on greenhouse gas emission is included in GWP cost via the changes in amount of CH_4 and N_2O emissions.

For full search strategy, searching research studies were undertaken in 2 online databases including ScienceDirect and Scopus. the terms used to conduct the searches were “Greenhouse gas emission”, “rice”, “paddy”, “Net Ecosystem Economic Budget”, and “NEEB”. The Boolean search operators which are “AND” and “OR” were also employed to combine the search terms.

Inclusion criteria were studies which:

- include rice in the experiments
- evaluate Net Ecosystem Economic Benefit (NEEB)
- are written in English

Exclusion criteria were studies which:

- does not include rice in the experiments
- do not report Net Ecosystem Economic Benefit (NEEB)
- are not written in English

CHAPTER V RESULTS

5.1 Results from Panel Regression Analysis

5.1.1 Descriptive Statistics

Descriptive statistics of variables are summarized in table 14. Greenhouse gas emission per capita is 2.32 tons of greenhouse gas on average. It varies by provinces, ranging from 0.22 to over 10 tons per capita. The real rice production value of each province is about 1,290 million baht and also greatly varies with the standard deviation value of about 1,343 million baht. The average of share of industrial sector and population density are 24.28% and 237.83 persons per squared kilometers, respectively. For other rice production statistics, the average rice field size is about 2.58 hectares per household with the maximum value of 6.09 hectares. About 93% on average are fertilized rice fields with only small deviation of 5.5%. It means that Thai rice farmers apply fertilizers to most of their rice fields. Lastly, similar to real rice production value, the number of rice farmer household greatly varies, ranging from 7 to over 243,000 households per province with the average of about 48,890 households per province.

Table 14 Descriptive statistics of variables

Variable	**Mean**	**Median**	**Maximum**	**Minimum**	**S.D.**
GHG	2.32	1.76	10.61	0.22	1.98
RGPP	1,290.2	824.89	6696.1	0.075	1,343.8
INDUSTRIAL	24.28	17.03	82.71	3.10	19.40
POPDENSITY	237.83	122.27	3,631.20	19.27	472.48
ENERGY	0.39	0.32	3.02	0.06	0.31
RLAND	2.58	2.60	6.09	0.59	1.15
Fertilizer	93.06	94.58	99.90	68.04	5.50
RHH	48,891.82	27,290.5	243,328	7	55,819.21

5.1.2 Regression Models

5.1.2.1 Regression Models for all provinces in Thailand

Table 15 shows the squared and cubic polynomial regression models for all provinces in Thailand estimated by OLS, FEM, REM, and TSLS with White's robust standard error as autocorrelation is detected in all models at 1% significance level.

From the cubic polynomial regression model, Durbin-Wu-Hausman Test indicates that it is failed to reject the null hypothesis of that lnRGPP, $(lnRGPP)^2$, $(lnRGPP)^3$ are exogenous at 10% significant level, so the relationship between the greenhouse gas emission per capita and the real value of rice production is not bidirectional in this study. This is possible as climate change is a global phenomenon and the contribution of greenhouse gas from Thailand is relatively small. Additionally, climate change gradually takes effects over a long period of time. Thus, its impact cannot be clearly observed in this study. Next, from Hausman test, the null hypothesis can be rejected at 1% significant level, so FEM is preferred to REM. Additionally, F-statistics significance test for cross-section fixed effects indicates that fixed effects are jointly statistically significant at 1% significant level, so FEM is preferred to pooled OLS. Therefore, equation (1) by FEM is selected to be interpreted as there is not a simultaneity bias, and it is preferred to REM and pooled OLS.

From the squared polynomial regression model, with similar results from Durbin-Wu-Hausman Test, Hausman Test, and F-statistics for cross-section fixed effects, FEM is also the most appropriate model with White's robust standard error. Whether to select FEMs from the cubic or squared polynomial regression model depends on 3 criteria which are statistical significance of $(lnRGPP)^3$, AIC, and SIC. From the cubic model, $(lnRGPP)^3$ is statistically significant at 1% significant level. Both AIC and SIC value from the cubic model are also lower than those of the squared model. Thus, the cubic polynomial regression model is preferred to the squared model.

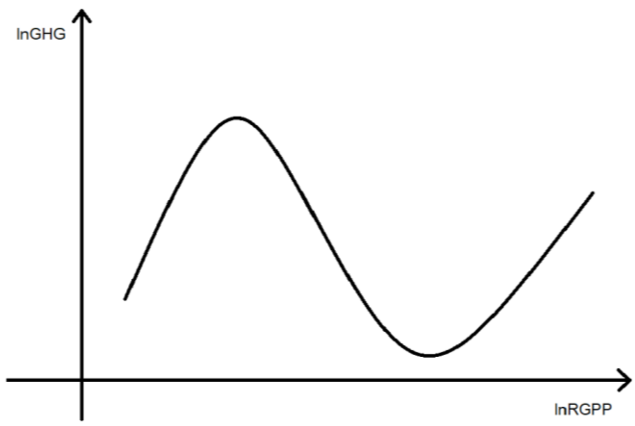
Table 15 Estimation of polynomial regression models for all provinces in Thailand

Polynomial Regression	**Cubic Polynomial Regression**				**Squared Polynomial Regression**			
Estimation Method with robust standard error:	**Pooled OLS**	**REM**	**FEM**	**TSLS**	**Pooled OLS**	**REM**	**FEM**	**TSLS**
Independent Variables								
Constant	2.814*** (0.192)	2.326*** (0.393)	-13.218*** (3.379)	-13.495** (6.858)	2.773*** (0.206)	2.180*** (0.450)	-15.515*** (3.556)	-15.106*** (3.967)
lnRGPP	0.048* (0.027)	0.086 (0.060)	0.264 (0.200)	0.172 (2.289)	-0.139*** (0.050)	-0.243*** (0.084)	-0.364*** (0.135)	-0.346 (0.829)
$(lnRGPP)^2$	-0.114*** (0.010)	-0.134*** (0.019)	-0.117** (0.049)	-0.092 (0.530)	-0.005 (0.005)	0.009 (0.008)	0.047*** (0.014)	0.039 (0.109)
$(lnRGPP)^3$	0.010*** (0.001)	0.012*** (0.002)	0.011*** (0.004)	0.009 (0.034)				
lnPOPDENSITY	0.080*** (0.028)	0.139** (0.054)	2.901*** (0.698)	2.986* (1.570)	0.017 (0.030)	0.094 (0.061)	3.406*** (0.737)	3.369*** (0.758)
lnINDUSTRIAL	0.221*** (0.040)	0.178** (0.073)	0.008 (0.172)	-0.018 (0.334)	0.179*** (0.045)	0.146* (0.082)	-0.076 (0.170)	-0.086 (0.238)
lnENERGY	0.474*** (0.061)	0.402*** (0.117)	0.242* (0.136)	0.241 (0.168)	0.565*** (0.069)	0.412*** (0.129)	0.239* (0.136)	0.241 (0.170)
TIME	-0.097*** (0.013)	-0.092*** (0.008)	-0.087*** (0.011)	-0.090*** (0.027)	-0.102*** (0.014)	-0.094*** (0.008)	-0.087*** (0.012)	-0.092*** (0.028)
F-statistics	144.947***	46.234***	56.841***	53.817***	121.635***	37.587***	56.463***	54.611***
Pesaran CD test for cross-sectional dependence	26.438***	26.607***	22.009***	21.589***	24.624***	23.715***	18.252***	18.296***
AIC			0.181				0.196	
SIC			0.933				0.939	
Difference in J-statistics from Durbin-Wu-Hausman Test	0.087				0.417			
Chi-squared statistics from Hausman Test	34.839***				56.534***			
F-statistics for cross-section fixed effects	15.754***				20.234***			
Breusch-Pagan LM Test for random effects	550.095***				605.939***			

Note: Values in parentheses are robust standard errors. (*), (**), and (***) represent statistical significance at 10%, 5%, and 1% level, respectively. Fixed effects are also included in TSLS models as they are statistically significant at 1% significance level.

From the cubic model, although lnRGPP is not statistically significant, its squared and cubed terms are statistically significant at 5% and 1% significant level. As the coefficient signs of lnRGPP, $(\ln RGPP)^2$, and $(\ln RGPP)^3$ are positive, negative, and positive, respectively, the real rice production value shows a N-pattern relationship with the greenhouse gas emission per capita as shown in figure 15. This pattern divides the relationship into 3 phrases. At first, an expansion of rice production will lead to higher emission. After the highest turning point, it would enter the second phrase. A further growth will reduce the emission. Then, after the lowest turning point is reached, it will enter the third phrase as further growth would lead to higher emission again. This aligns with the explanation from Dinda (2004) that a N-pattern relationship shows a temporary improvement of the environment from the first to the second phrase. However, due to difficulty in keeping up efficiency improvement with expanding production, the curve later swings upward in the third phrase.

Figure 15 The pattern of relationship between lnRGPP and lnGHG for all provinces in Thailand



Additionally, the first and second turning points occurs when the real rice production values are 4.086 and 293.909 million baht with 2002 as a reference year, respectively. Comparing with the average rice production value per province in 2017, which is 1,204.6 million baht, it can be said that in that year, rice expansion in

Thailand had exceeded the second turning points so far, and further growth in the economic activity leads to an increase in greenhouse gas emission per capita. In detail, only 4 provinces had the real rice production value below the first turning points. Those provinces are Phuket, Ranong, Phangnga, and Krabi which are all in southern region. Other 19 provinces had the values between the first and second turning points. Lastly, the remaining 54 provinces already had the values beyond the second turning point. Therefore, rice production expansion in most provinces can lead to higher greenhouse gas emission per capita.

For other variables, population density is statistically significant at 1% significant level and is positively related to greenhouse gas emission per capita. If population density increases by 1%, greenhouse gas emission per capita will also increase by 2.9%. This finding is similar to that of Grossman and Krueger (1991) who found higher concentration of pollution in more densely populated density and that of Managi and Jena (2008) who found worsened air pollutions of SO_2, NO_2, and SPM for more densely populated cities in India.

Although industrial share is not statistically significant at 10% significant level, its sign is positive as expected. Higher proportion of industrial share can lead to higher greenhouse gas emission per capita. Additionally, the positive, statistically insignificant relationship is also found in other countries such as Argentina, Japan, Mexico, and Republic of Korea (Özbuğday & Erbas, 2015).

The commercial energy consumption from oil is statistically significant at 10% and is positively related to greenhouse gas emission per capita as expected. A 1% increase in the consumption leads to 0.24% increase in the greenhouse gas emission per capita. This aligns with the findings from Baek (2015); Jalil and Mahmud (2009); Saraç and Yağlikara (2017) that energy consumption is positively related to CO_2 emission, one of greenhouse gas emission.

Time, as a proxy for technological advancement and environmental awareness, shows a statistically significant, negative relationship with the greenhouse gas emission per capita at 1% significant level. Holding other variables constant, the emission decreases by about 8% annually.

5.1.2.2 Regression Models for top 72 provinces in Thailand

Next, as some provinces have relatively much lower rice production values than others, top 72 provinces are selected to estimate the models, excluding 5 provinces whose annual real rice production value is lower than 10 million baht on average from 2012 to 2017. Table 16 shows the squared and cubic polynomial regression models for the top 72 provinces in Thailand estimated by OLS, FEM, REM, and TSLS with White's robust standard error as autocorrelation is detected in all models at 1% significance level.

For both squared and cubic polynomial regression models, Durbin-Wu-Hausman Test, Hausman Test, and F-statistics for cross-section fixed effects indicate that FEM is the most appropriate model. Since Durbin-Wu-Hausman Test fails to reject the null hypothesis at 10% significant level, only one-way casual effect from rice production to greenhouse gas emission can be found. That is, it is not the bidirectional relationship in this study. To consider whether squared or cubic polynomial regression model is more appropriate, statistical significance of $(\ln RGPP)^3$, AIC, and SIC are considered. In cubic model, the cubic term of lnRGPP is not statistically significant at 10% significant level. Although AIC value from the squared model is slightly higher than that of the cubic model by 0.001, the SIC value from the squared model is relatively higher than that of the cubic model by 0.008. Since SIC imposes harsher penalty for an additional regressor than AIC, and the cubic term of lnRGPP is not statistically significant, it can be concluded that FEM of squared polynomial regression model is the most appropriate model to be interpreted.

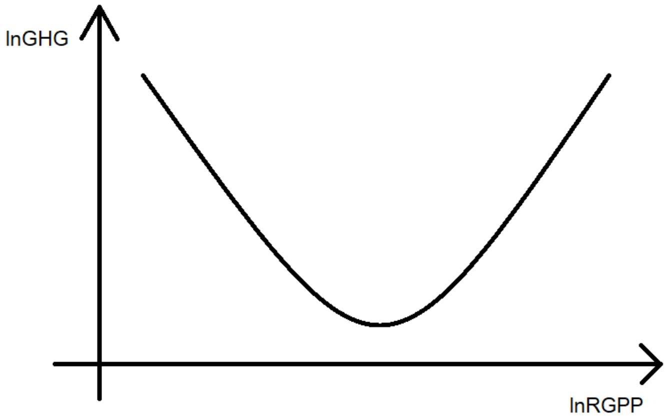
From the model, the coefficients of lnRGPP and $(\ln RGPP)^2$ are negative and positive respectively, so the relationship between the rice production value and greenhouse gas emission per capita can be described by U-shaped pattern as shown in figure 16. During the first phrase of the production expansion, the emission tends to decrease over time until reaching the turning point. After the turning point, further expansion leads to an increase in the emission. This indicates the unsustainability of rice production in Thailand in the term of climate change contribution. Same as the result from the model of all provinces in Thailand, the rice production should be improved to be more environmentally friendly.

Table 16 Estimation of polynomial regression models for top 72 provinces in Thailand

Polynomial Regression	**Cubic Polynomial Regression**				**Squared Polynomial Regression**			
Estimation Method with robust standard error:	**Pooled OLS**	**REM**	**FEM**	**TSLS**	**Pooled OLS**	**REM**	**FEM**	**TSLS**
Independent Variables								
Constant	1.312 (1.043)	1.343 (0.940)	-12.226*** (3.512)	-10.076* (5.436)	4.233*** (0.392)	3.903*** (0.636)	-12.521*** (3.551)	-9.229* (5.514)
lnRGPP	1.053* (0.613)	0.901* (0.533)	0.239 (0.683)	2.086 (4.761)	-0.829*** (0.132)	-0.868*** (0.170)	-0.643*** (0.176)	-1.347 (1.372)
$(lnRGPP)^2$	-0.303*** (0.110)	-0.291*** (0.103)	-0.122 (0.142)	-0.549 (0.937)	0.056*** (0.110)	0.063*** (0.014)	0.067*** (0.017)	0.143 (0.164)
$(lnRGPP)^3$	0.021*** (0.006)	0.022*** (0.006)	0.012 (0.009)	0.041 (0.054)				
lnPOPDENSITY	0.069** (0.030)	0.110** (0.056)	2.766*** (0.704)	1.939 (1.257)	0.079*** (0.029)	0.118** (0.058)	3.034*** (0.711)	2.654*** (0.814)
lnINDUSTRIAL	0.258*** (0.043)	0.260*** (0.074)	0.102 (0.203)	0.246 (0.332)	0.247*** (0.043)	0.215*** (0.077)	0.065 (0.199)	0.180 (0.317)
lnENERGY	0.450*** (0.063)	0.370*** (0.118)	0.271* (0.139)	0.245 (0.222)	0.448*** (0.066)	0.419*** (0.123)	0.295** (0.143)	0.365* (0.199)
TIME	-0.101*** (0.013)	-0.098*** (0.008)	-0.094*** (0.012)	-0.083** (0.035)	-0.108*** (0.013)	-0.104*** (0.008)	-0.097*** (0.012)	-0.087** (0.034)
F-statistics	119.482***	44.064***	49.211***	47.062***	130.675***	47.521***	49.690***	47.726***
Pesaran CD test for cross-sectional dependence	24.387***	24.269***	20.513***	21.092***	24.974***	25.171***	20.400***	23.170***
AIC			0.222				0.223	
SIC			0.966				0.958	
Difference in J-statistics from Durbin-Wu-Hausman Test	1.217				1.298			
Chi-squared statistics from Hausman Test	21.461***				27.552***			
F-statistics for cross-section fixed effects	14.888***				15.710***			
Breusch-Pagan LM Test for random effects	510.093***				521.113***			

Note: Values in parentheses are robust standard errors. (*), (**), and (***) represent statistical significance at 10%, 5%, and 1% level, respectively. Fixed effects are also included in TSLS models as they are statistically significant at 1% significance level.

Figure 16 The pattern of relationship between lnRGPP and lnGHG for top 72 provinces in Thailand



Additionally, the turning point can be calculated and is equal to 121.33 million baht with 2002 as a reference year. In 2017, the rice production values for 14 provinces are in the first phrase of the curve while the remaining 58 provinces are in the second phrase. Thus, similar to the result from the model of all provinces, rice productions in most provinces are already in the stage that further growth in rice production value leads to higher greenhouse gas emission.

For other variables, population density is statistically significant at 1% significance level. If the population density increases by 1%, the greenhouse gas emission per capita will increase by about 3%, which is 0.1% higher than the effect estimated based on all provinces.

The share of industrial sector is not statistically significant at 10% significance level and is positively related to the emission, same as the estimation from the model including all provinces.

Final commercial energy consumption from oil is statistically significant at 5% significant level and is positively related to the greenhouse gas emission per capita. If the energy consumption from oil increases by 1%, the emission per capita will increase by 0.295%. The effect is also larger than estimation based on all provinces.

Holding other variables constant, time trend shows about 9.7% decrease in the greenhouse gas emission per capita annually. This is higher than the estimation from the model with all provinces.

5.1.2.3 Regression Models for 22 provinces in Chao Phraya Basin area

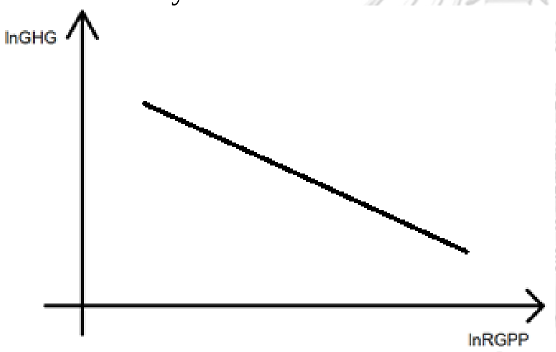
As 22 provinces in Chao Phraya Basin area, which are Tak ,Phichit, Sukhothai, Kam Phaeng Phet ,Phitsanulok ,Nakhon Sawan ,Uttaradit ,Ang Thong, Lop Buri ,Chai Nat ,Singburi ,Saraburi ,Suphan Buri ,Phra Nakhon Sri Ayuthaya ,Pathum Thani ,Nonthaburi ,Nakhon Pathom ,Chachoengsao ,Nakhon Nayok ,Samut Prakan, Samut Sakhon ,and Bangkok (Royal Irrigation Department of Thailand, 2020) mostly in Lower Northern and Central regions, tend to have high proportion of irrigated area, they are, therefore, selected to estimate the models. Table 17 shows the squared and cubic polynomial regression models for the 22 provinces located in the area estimated by OLS, FEM, REM, and TSLS with White's robust standard error as autocorrelation is detected in all models at 1% significance level.

For both squared and cubic polynomial regression models, Durbin-Wu-Hausman Test, Hausman Test, and F-statistics for cross-section fixed effects indicate that FEM is the most appropriate model. Since Durbin-Wu-Hausman Test fails to reject the null hypothesis at 10% significant level, only one-way casual effect from rice production to greenhouse gas emission can be found. Next, statistical significance of $(\ln RGPP)^3$, AIC, and SIC are considered. In cubic model, $(\ln RGPP)^3$ is not statistically significant at 10% significant level. Although AIC value from the squared model is slightly higher than that of the cubic model by 0.001, the SIC value from the squared model is relatively lower than that of the cubic model by 0.02. As SIC imposes harsher penalty, and the cubic term of lnRGPP is not statistically significant, it can be concluded that FEM of squared polynomial regression model is the most appropriate model to be interpreted.

From the model, the coefficients of lnRGPP and $(\ln RGPP)^2$ are negative and positive respectively, but coefficient of $(\ln RGPP)^2$ is not statistically significant at

10% significance level, so the relationship between the rice production value and greenhouse gas emission per capita can be described by a linear, decreasing trend as shown in figure 17. The result suggests that production expansion or a growth in rice production can lead to lower greenhouse gas emission per capita. The coefficient value of lnRGPP is equal to -0.59, statistically significant at 10% significance level. It means a 1% increase in rice production value leads to a 0.59% reduction in greenhouse gas emission per capita. This indicates the rice production of Thailand in this area is sustainable in the term of climate change contribution. It can be due to better water management enabled by irrigation area as these provinces are in Chao Phraya Basin area.

Figure 17 The pattern of relationship between lnRGPP and lnGHG for 22 provinces in Chao Phraya Basin area



For other variables, population density is statistically significant at 5% significance level. If the population density increases by 1%, the greenhouse gas emission per capita will increase by 1.96%, which is about 1% lower than the effect estimated based on all provinces.

The share of industrial sector is statistically significant at 5% significance level and is negatively related to the emission. The coefficient is equal to -0.532. That is, a 1% increase in industrial sector can lead to a reduction in greenhouse gas emission per capita by about 0.53%. Özbuğday and Erbas (2015) also found this type of relationship for some countries such as Norway, South Africa, and Turkey, and explained that it could be due to the adoption of clean industrial production process.

Another possible reason is that the industry type would be labor intensive rather than capital intensive. As a result, it generates relatively less pollution.

Final commercial energy consumption from oil is statistically significant at 5% significant level and is positively related to the greenhouse gas emission per capita. If the energy consumption from oil increases by 1%, the emission per capita will increase by 0.77%. The effect is over 0.5% higher than estimation based on all provinces.

Holding other variables constant, time trend shows about 11.9% decrease in the greenhouse gas emission per capita annually which is a bigger reduction than the estimation from the model with all provinces.

Table 17 Estimation of polynomial regression models for 22 provinces located in Chao Phraya Basin area

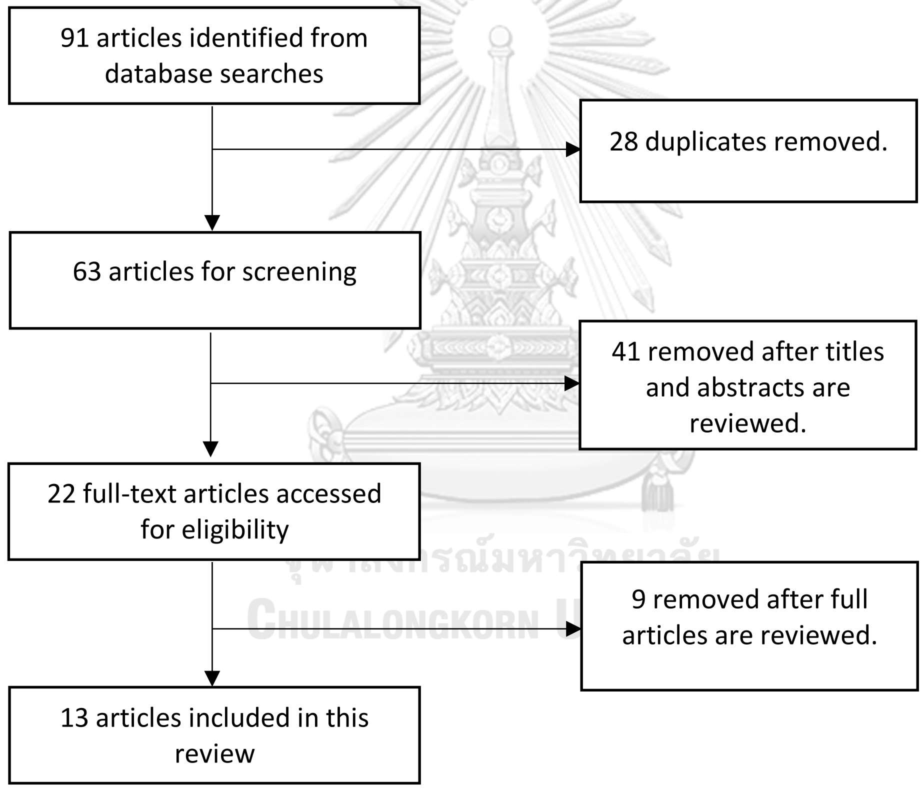
Polynomial Regression	**Cubic Polynomial Regression**				**Squared Polynomial Regression**			
Estimation Method with robust standard error:	**Pooled OLS**	**REM**	**FEM**	**TSLS**	**Pooled OLS**	**REM**	**FEM**	**TSLS**
Independent Variables								
Constant	0.632 (1.315)	0.875 (1.590)	-9.714* (5.274)	-10.088 (9.253)	3.270*** (0.343)	3.681*** (0.549)	-7.954 (4.904)	-9.812 (6.807)
lnRGPP	0.726 (0.697)	0.709 (0.846)	1.111 (1.285)	-0.786 (8.461)	-0.717*** (0.106)	-0.855*** (0.154)	-0.590* (0.343)	-0.238 (0.535)
$(lnRGPP)^2$	-0.185 (0.122)	-0.200 (0.152)	-0.272 (0.251)	0.107 (1.775)	0.060*** (0.009)	0.071*** (0.013)	0.050 (0.033)	-0.006 (0.057)
$(lnRGPP)^3$	0.013* (0.007)	0.015* (0.009)	0.018 (0.015)	-0.007 (0.112)				
lnPOPDENSITY	0.098*** (0.026)	0.098** (0.041)	1.828** (0.864)	2.510 (3.248)	0.102*** (0.027)	0.098** (0.042)	1.963** (0.829)	2.336** (1.094)
lnINDUSTRIAL	0.161*** (0.055)	0.116 (0.085)	-0.444 (0.274)	-0.826 (1.042)	0.137*** (0.051)	0.087 (0.078)	-0.532** (0.243)	-0.768** (0.299)
lnENERGY	0.655*** (0.118)	0.700*** (0.175)	0.689** (0.270)	0.615* (0.341)	0.674*** (0.119)	0.740*** (0.173)	0.772** (0.264)	0.615* (0.333)
TIME	-0.114*** (0.015)	-0.112*** (0.014)	-0.117*** (0.020)	-0.158** (0.067)	-0.118*** (0.014)	-0.117*** (0.013)	-0.119*** (0.020)	-0.154*** (0.031)
F-statistics	54.038***	30.374***	22.758***	22.403***	61.839***	35.110***	23.382***	23.457***
Pesaran CD test for cross-sectional dependence	5.524***	5.655***	3.279***	5.038***	5.501***	5.689***	3.512***	4.985***
AIC			0.002				0.003	
SIC			0.635				0.615	
Difference in J-statistics from Durbin-Wu-Hausman Test	5.452				3.932			
Chi-squared statistics from Hausman Test	14.660**				14.417**			
F-statistics for cross-section fixed effects	75.688***				76.239***			
Breusch-Pagan LM Test for random effects	17.395***				18.339***			

Note: Values in parentheses are robust standard errors. (*), (**), and (***) represent statistical significance at 10%, 5%, and 1% level, respectively. Fixed effects are also included in TSLS models as they are statistically significant at 1% significance level.

5.2 Results from Systematic Review

From the strategic searches specified in the previous chapter, 91 researches articles were found from 2 databases. 28 articles were removed as duplicates, and 41 were excluded after the titles and abstracts were reviewed due to irrelevance. 22 are accessed for eligibility, and 9 are excluded after full-article review. The remaining 13 articles are included in this result.

Figure 18 Article selection flow



All 13 articles apply experiments to observe the impact of particular farm practices on rice production, with other crops in some articles. Table 18 summarizes recommended farm practices based on NEEB value from the articles. Overall, experiments from 12 out of the 13 articles take place in China while an experiment from only 1 article is in India. Farm practices from all article can be broadly classified into 5 groups. The main results are concluded in three parts for each research which are the impact of the practice on greenhouse gas emission; the impact on farm income through changes in rice yield, revenue, and cost; and the impact on NEEB value.

5.2.1 Tillage

Past related researches from the systematic review have shown and provided the same impacts of tillage management on greenhouse gas emission and income for farmers. Both Z. S. Zhang et al. (2015) and Z. S. Zhang, Chen, Liu, Cao, and Li (2016) found that in term of greenhouse gas emission, tillage practice in paddy fields can emit more CH_4 than without the practice, but it does not affect the amount of N_2O emission. The magnitudes of effects from both researches are also close to one another. Z. S. Zhang et al. (2015) found that no-tillage practice can decrease CH_4 emission by 7.5% while Z. S. Zhang et al. (2016) found the figure to be 8.5%-13.7%. In term of farm income, the practice can increase expense from mechanical tillage, but tillage does not affect crop yield which, in turn, cannot increase the revenue, so it results in a decrease in farm income. No-tillage practice can save farmers 1,200-2,400 Chinese Yuan/hectare/year. As an indicator of balance between greenhouse gas emission and farm income, NEEB indicates that no-tillage provides higher NEEB value than tillage practice, by 9.1-15.6%, as no-tillage decreases GWP cost from greenhouse gas emission and cost from mechanical tillage.

5.2.2 Straw Management

The overall impact of straw management is still controversial. In the aspect of greenhouse gas emission, By returning straw to paddy fields, Z. S. Zhang et al. (2015) found that it does not affect the amount of N_2O emission. Meanwhile, Z. Sun et al. (2019) found it increases the emission by about 6-23%, but Li, Guo, Cao, and Li (2021) found the opposite impact that it decreases the emission by 3-31%. On the other hand, there is a consensus that straw returning can significantly increase CH_4 emission from the paddy fields. Both Z. S. Zhang et al. (2015) and Z. Sun et al.

(2019) found the practice to increase the emission by more than 30% while Li et al. (2021)'s finding ranges 5.7-73.3%, depending on straw returning level.

In farm income aspect, Z. S. Zhang et al. (2015) and Z. Sun et al. (2019) indicates no impact of straw returning on rice yields. However, Li et al. (2021) found that straw returning can increase the rice yield. To further extent, Li et al. (2021) experiments 3 different proportions of straw returning to the fields which are returning all preceding crop straw to the field, returning two-thirds of preceding crop straw to the field, and returning one-third of preceding crop straw to the field. It is found that the proportion of straw returning does not affect rice yield. All straw returning levels increase the rice yield by 8.1%-9.9%.

In term of NEEB, Z. S. Zhang et al. (2015) and Z. Sun et al. (2019) obtained the same results from the experiments that straw returning does not affect NEEB. Nevertheless, Li et al. (2021) has found that NEEB can be significantly affected by straw returning levels. Returning one-third of preceding crop straw results in the highest NEEB value, increasing by 18.7% compared to no straw returning practice. It is worth to note that although straw returning level does not affect rice yield, it affects the amount of greenhouse gas emission.

5.2.3 Fertilizer

Fertilizers have been researched for its impact on greenhouse gas emission and income from rice production. Although selected researches shared the same conclusion that fertilizer can increase N_2O emission, their focuses are much different from one to another.

Z. S. Zhang et al. (2016) has tested the effects of chemical, organic, and slow-release Nitrogen (N) fertilizers on greenhouse gas emission from rice paddy fields with different combinations and proportions. All fertilizer types increase both CH_4 and N_2O emission with different magnitudes. Among all tests, 100% organic N fertilizer results in the highest increase in CH_4 emission by more than 50%, and the combination of 50% organic and 50% chemical N fertilizer results in the highest increase in N_2O emission by over 250% compared to no-N fertilizer case. Relative to no fertilizer, the combination of 50% slow-release fertilizer and 50% chemical N fertilizer results in the least increase in the greenhouse gas emissions. In term of rice yield, all fertilizer types can increase the yield compared to no-fertilizer case, and there is no difference between organic and chemical N fertilizer. The combination of 50% slow-release fertilizer and 50% chemical N fertilizer gives the highest yield, an increase of 26.9-30.4% compared to the no-fertilizer case, followed by the combination of 50% organic and 50% chemical N fertilizer providing an increment of 18.9-27.7%. In term of NEEB, the combination of 50% organic and 50% chemical N fertilizer gives the highest value of NEEB. It is worth to note that the combination results in the second highest GWP cost. Although the combination between 50% slow-release and 50% chemical N fertilizer can result in the lowest GWP cost, its NEEB value lower by about 60% compared to no-N fertilizer case is the lowest due to too high fertilizer cost.

Similarly, L. Sun, Deng, Fan, Li, and Liu (2020) found that urea, as N fertilizer, can significantly increase N_2O emission by more than 120% though it doesn't affect CH_4 emission. The fertilizer can enhance yields by 44.4% and, consequently, NEEB by more than 135% because of its positive effects on income from yield.

Meanwhile, Liu et al. (2020) focuses on how fertilizer is applied to the rice field. Urea Deep Placement (UDP) and Urea Broadcasting (UBC) are compared. It is found that UDP results in lower CH_4 and N_2O emission by 36-39% and 29-31%, respectively, than UBC. In addition, yield from UDP is also higher than UBC. Thus, NEEB value from UDP is higher than UBC by 45%. Nevertheless, Liu et al. (2020) extends the scope of greenhouse gas sources and found that although UDP emits less CH_4 and N_2O than UBC, it consumes more energy from diesel used in field machinery operation. As a result, UDP results in more greenhouse gas emission when extending the scope of study as it generates more CO_2 emission than UBC.

G. Zhang et al. (2018) tested the effect of controlled release fertilizer (CRF) under plastic mulching cultivation. It is found that even though CRF can reduce both

CH_4 and N_2O emission by 1-10% and 11-42%, respectively, and increase yields by 1-5%, it decreases NEEB value because the fertilizer cost is too high.

Singh, Benbi, and Verma (2020) has focused on the effect of nutrient management through fertilizers and farmyard manure on greenhouse gas emission and yield from rice production. It is found that when the balanced applications of nitrogen (N), phosphorus (P), and potassium (K) are provided along with farmyard manure to rice production, it will result in the highest GWP value among all nutrient management scenarios in the research which is about 28% higher than unfertilized control but also provide the highest rice yields, 58% higher. Despite of the highest GWP value, it is considered to be recommended practice as NEEB value can be increased by the balanced application of nutrients and manure, relative to other nutrient management techniques such as unfertilized control or sole application of N. Furthermore, the balance nutrients along with manure also has the lowest value of greenhouse gas intensity, which means the lowest greenhouse gas emission per unit of grain produced.

5.2.4 Animal Farming Integration

Past researches from the systematic review are vastly diversified, focusing on different animal species to be used in rice production.

Fang et al. (2021) has investigated whether integrated rice-frog farming can provide the sustainability between greenhouse gas mitigation and farm income. Multiple scenarios with different densities of frogs in paddy fields are also experimented. In the term of the mitigation, it is found that releasing frogs into rice field can decrease both CH_4 and N_2O emission by 23.6-45.4% and 1.84-22.33%, respectively. More number of frogs lead to lower greenhouse gas emission. In term of the income, both rice yield and cost depend on frog densities. On average the yield increases by 57.8%. It is found that frog densities between 15,000 and 30,000 frogs per hectare are the most potential number to achieve the highest rice yield. Meanwhile, too many frogs can lead to too high cost and, consequently, business loss.

The experiment indicates that the frog density of 60,000 frogs per hectare can lead to business loss as the cost exceeds revenue. Furthermore, integrated rice-frog farming can improve the rice quality increasing the price to be higher than conventional rice as it is an ecological product with a premium. The highest NEEB value can be achieved with the frog density of 15,000 frogs per hectare.

Wang, Ma, Xu, and Lu (2019) investigated the impact of crab integration into rice paddy fields. Releasing crabs into the fields can simultaneously increase CH_4 by 29.2-36.8% and decrease N_2O emission by 19.7-28.2%. However, to the total contribution of greenhouse gas as measured in GWP, CH_4 accounts for over 95% while N_2O accounts for less than 5%. Thus, releasing crabs into the field increases greenhouse gas emission. In the term of farm income, including crabs can also increase rice yields, and crabs can also be sold for additional income. To achieve higher NEEB compared to rice monoculture, including megalopa or juvenile crabs can increase the NEEB as the increase in rice yield and additional income from crab output can outweigh the additional cost and more greenhouse gas emission. Megalopa crabs can generate higher NEEB than juvenile crabs. Although rice-crab farming can increase NEEB by 53.07% and 23.68% for megalopa and juvenile crabs, respectively; it is worth to note that it emits more greenhouse gas emission than rice monoculture.

Z. Sun et al. (2019) integrated crayfish into rice paddy fields. Crayfish can decrease CH_4 emission by 18.1-19.6% and increase N_2O emission by 16.8-21.0%. Feeding them with forage can further decrease CH_4 by 13.9-18.7% but also increase N_2O emission by 24.4-33.2% compared to no feeding. Compared to rice monoculture, crayfish and feeding of forage can decrease GWP. In the term of farm income, rice-crayfish farming reduces rice yield by about 31%, increases revenue from selling crayfish, and increases cost through crayfish cost. In all, NEEB from rice-crayfish farming is higher than rice monoculture by 26.9-75.6%. The value can be further enhanced with feeding of forage by 45.1-123.0%.

Sheng, Cao, and Li (2018) integrated duck into rice paddy fields. Introduction of ducks decreases CH_4 emission by more than 30% but drastically increases N_2O emission. In total, the practice decreases GWP by about 28%. In term of farm income, ducks can increase the rice yield by enhancing tiller number and root bleeding rate. In all, rice-duck farming practice can increase the value of NEEB by about 40% compared to without ducks.

5.2.5 Others

There are also more various farming practices balancing between environmental and economic aspects. One of them from systematic review is biochar. Biochar can be derived from rice or wheat straw by pyrolysis at high temperature. L. Sun et al. (2020) and Bi et al. (2019) applied biochar to rice production and observed its effects on greenhouse gas emission and rice yield. Although the results from both researches are different for its effect on greenhouse gas emission, the results align in term of economic aspects. L. Sun et al. (2020) found that biochar increases N_2O emission by 13.7-38.1% while the amount of CH_4 emission is not affected. Meanwhile, Bi et al. (2019) found that biochar can decrease both N_2O and CH_4 emission. The effects depend on soil types. In term of economic and NEEB, both L. Sun et al. (2020) and Bi et al. (2019) found that biochar can increase rice yields. However, biochar is too expensive such that it significantly reduces NEEB and farm profit. Although applying biochar to paddy soil doesn't increase rice yield enough to compensate with higher cost, resulting in lower NEEB; biochar applied to upland soil can increase rice yield enough to offset biochar cost and results in higher NEEB than without biochar (Bi et al., 2019).

G. Zhang et al. (2018) compared plastic film mulching cultivation enhanced with urease and nitrification inhibitors (UNIs) to rainfed and traditional irrigation. At the first step, applying plastic film mulching can increase N_2O relative to both rainfed and traditional irrigation by 77% and more than 200%, respectively. However, mulching can decrease CH_4 emission relative to traditional irrigation by 45-85%, but its effects on CH_4 emission compared to rainfed is inconclusive. Plastic mulching results in significantly higher rice yield by 7-148% than rainfed but slightly lower than traditional irrigation by 3-10%. Among the three methods, plastic mulching has the highest NEEB value. At the second step, UNIs such as hydroquinone (HQ), dicyandiamide (DCD), and chlorinated pyridine (CP) with N fertilizer are applied for plastic film mulching cultivation. Although these UNIs can decrease both CH_4 and N_2O emission, except DCD which only decreases N_2O; their costs are too high such that it reduces NEEB value. Only CP can increase yield, decrease greenhouse gas emission, and increase NEEB simultaneously. The application of CP can further increase NEEB by about 210 Chinese Yuan/hectare/year from plastic mulching practice.

Cai, Pittelkow, Zhao, and Wang (2018) studied the impact of rotating rice production with other plants which are wheat, rape, fava bean, and milk vetch. It is found that rotating rice with the other 4 plants does not affect the amount of CH_4 emission. The difference lies in the amount of N_2O emission. Rice-fava bean and rice-milk vetch rotations generate less N_2O emission than rice-wheat and rice-rape rotations by about 40-64%. The reason for less emission comes from the reduction of fertilizer application for winter legume-rice rotations. In term of farm income, rice-wheat generates the highest grain yield revenue. However, it also incurs the highest environmental cost. Meanwhile, rice-fava bean rotation generates less income but also less environmental cost. The NEEB value of the two combinations are, thus, comparable. Compared to the two combinations, the value of NEEB from rice-milk vetch is significantly lower about 6-37%. In all, the research highlights the potential tradeoff between economic and environmental benefits. Winter legume-rice is less attractive for farmers than rice-wheat due to relatively less income. However, as winter legume is more environmentally friendly, the government may focus on further research to improve the legume yields and farmers' income.

Table 18 Summary of articles in systematic review

No.	Author (year)	Country	Plant	Category					Farm practice with the highest NEEB value
				Tillage	Straw Management	Fertilizer	Animal Farming Integration	Others	
1	Z. S. Zhang et al. (2015)	Hubei province, China	Rice-wheat	✓	✓				No tillage and no straw returning
2	Z. S. Zhang et al. (2016)	Hubei province, China	rice - oilseed rape	✓		✓			50% organic and 50% chemical nitrogen fertilizer and no tillage
3	Fang et al. (2021)	Shanghai, China	Rice				✓		Rice field with 15,000 frogs per hectare
4	Wang et al. (2019)	Liaoning province, China	Rice				✓		Rice field with megalopa crabs
5	G. Zhang et al. (2018)	Sichuan province, China	Rice			✓		✓	Plastic film mulching and Chlorinated pyridine (CP) application with nitrogen fertilizer
6	Z. Sun et al. (2019)	Hubei province, China	Rice		✓		✓		Rice field with crayfish, feeding forage, and straw returning

7	Liu et al. (2020)	Hubei province, China	Rice-rapeseed			✓			Urea Deep Placement (UDP)
8	L. Sun et al. (2020)	Jiangsu province, China	Rice			✓		✓	Nitrogen fertilizer without biochar
9	Bi et al. (2019)	Jiangsu province, China	Rice-wheat and millet-wheat					✓	Low amount of straw biochar application in acid upland soil
10	Li et al. (2021)	Hubei province, China	Rice-wheat		✓				Returning one-third of preceding crop straw
11	Sheng et al. (2018)	Hubei province, China	Rice				✓		Rice field with ducks
12	Singh et al. (2020)	Punjab state, India	Rice-Wheat			✓			Balanced application of nutrients (nitrogen, phosphorus, and potassium) along with manure
13	Cai et al. (2018)	China	Rice-wheat, rice-rape, rice-milk vetch, and rice-fava bean					✓	Rice-legume rotation (when legume yield is high)

CHAPTER VI DISCUSSION AND CONCLUSION

6.1 Discussion of Panel Regression Analysis

The first objective of this study is to examine the relationship between greenhouse gas emission and income from rice production of Thailand. To achieve the objective, panel regression analysis is applied to a dataset from 2012 to 2017 at provincial level of Thailand. Generally, the model can be estimated by OLS. However, if there is a two-way causality between the emission and the income from rice production, OLS will be biased, and TSLS should be applied instead. This study compares 4 models: TSLS, FEM, REM, and Pooled OLS.

Considering all 77 provinces in Thailand, the results show that there is only one-way casual effect from rice production to greenhouse gas emission, and the most appropriate model is FEM estimated by OLS. The real rice production value and greenhouse gas emission per capita in Thailand show a N-shape pattern with the first and second turning points at 4.086 and 293.909 million baht with 2002 as a reference year, respectively. This fits the explanation by Dinda (2004) that the EKC hypothesis can only describe a temporary improvement in the emission during the initial phrase of rice production expansion as eventually further growth of rice production in Thailand will lead to higher emission. The pattern is also the same as the finding from Lapinskienė et al. (2014) for the relationships between greenhouse gas emission and income per capita in Norway, Ireland, and Switzerland and the finding from Jafari et al. (2017) for the relationship between CO_2 emission and income per capita among developed economies. Apart from rice production, both population density and commercial energy consumption in oil can also increase the emission. For the population density, the finding aligns with that of Grossman and Krueger (1991) who found higher concentration of pollution with more densely populated density of countries around the world and that of Managi and Jena (2008) who found worsened air pollutions of SO_2, NO_2, and SPM for more densely populated cities in India. For the energy consumption in oil, the finding aligns with the results from Baek (2015);

Jalil and Mahmud (2009); Saraç and Yağlikara (2017) that energy consumption is positively related to CO_2 emission, one of greenhouse gas emission. Meanwhile, holding other factors constant, the emission decreases by about 8% annually, reflecting an adoption of more environmentally friendly technology and higher level of environmental awareness. This aligns with the hypothesis from Apergis and Ozturk (2015) for the time trend as technological advancement and Grossman and Krueger (1991) and Panayotou (1997) for the variable as rising environmental awareness over time.

Nevertheless, as some provinces in the country have relatively much lower value of rice production, the study also estimates the model from only top 72 provinces whose average real rice production value is more than 10 million baht per year from 2012 to 2017. Same as the model including all provinces, there is only one-way casual effect from the rice production to the emission, and the most appropriate model is FEM estimated by OLS. It is, however, found that for the 72 provinces, the relationship between the rice production and the emission per capita is better described as U-shape pattern with the lowest turning point to be at 121.33 million baht with 2002 as a reference year. The finding of the pattern is similar to the result from Moutinho et al. (2020) who found that the relationship between gross value added from the agricultural sector and CO_2 emission per capita among OPEC countries follows the U-shape pattern. Although the shape and turning point are different from the full model with 77 provinces, the graph shapes of models with 77 and 72 provinces align with each other. As 5 provinces with the lowest average rice production value are excluded in the second model, this is equivalent to exclude the first part of N-shape pattern in the first model, changing it to the U-shape pattern in the second model. For other factors, the directions of their relationships with the emission per capita remain the same as in the first model, and the magnitudes are also similar to the estimations from the first model.

To further extent, some provinces have relatively better water management because of accessibility to irrigation system. In this study, 22 provinces in Chao Phraya Basin area are also used as a dataset to estimate the models. Same as the previous two models, one one-way casual effect from the rice production to the emission is found, and the most appropriate model is FEM estimated by OLS. It is found that for the 22 provinces, the relationship between the rice production and the emission per capita is described as a linear, decreasing trend. It suggests that rice production in this area is sustainable in term of climate change contribution as a growth in the production can lead to lower greenhouse gas emission per capita. This can be associated with the explanation from Khalil and Aslam (2009) that one of the most important factors to determine the amount of greenhouse gas emission from rice field is water management. As these provinces relatively have more access to irrigated area than other provinces, they can effectively manage water in rice field which, therefore, decreases the emission. For other factors, population density, commercial energy consumption in oil, and time trend show the same directions of their relationships with the emission per capita as in the first model. However, the industrial share in these provinces shows a negative, statistical significance relationship with the emission, different from the first model. Özbuğday and Erbas (2015) found the same type of relationship in some countries such as Norway and explains that this can be due to an adoption of clean industrial production process or the industry is labor intensive rather than capital intensive, causing the emission to decline.

It is worth to remark that the effect of greenhouse gas emission on rice production is not clearly observed in this study due to many reasons. First of all, given the change in climate and weather over time, farmers also adapt themselves to suit with the new conditions to maintain rice yield and their incomes. For example, Kawasaki and Herath (2011) found that farmers in Khon Kaen province, Thailand, has selected different rice varieties, improved soil fertility, and shifted cultivation period to adapt with changing climate. Secondly, the climate change is a phenomenon at global level while the greenhouse gas emission in this study is only from Thailand, representing only small proportion of the total greenhouse gas emission. Specifically, the national emission is about only 1% of global greenhouse gas emission (Electricity Generating Authority of Thailand, 2016). Lastly, the climate change takes effect over a long period of time such as decades or centuries while the panel dataset in this study covers only 6 years. As a result, the feedback effect from greenhouse gas emission to rice production in Thailand is not explicitly shown in this study.

In all, from the results for the first objective, it is found that from 2012 to 2017 the growth of rice production in Thailand was not sustainable for the environment as further expansion shows an upward trend with more greenhouse gas emission. Current rice field management is not enough to sustainably reduce greenhouse gas emission per capita. More environmentally friendly rice farming practices are required. Nevertheless, scoping down to smaller area which is Chao Phraya Basin area, in this study, where more irrigated rice fields are relatively more accessible, it is found that the rice production is sustainable in term of climate change contribution.

6.2 Discussion of Systematic Review

The second objective of this study is to study and gather information about greenhouse gas mitigation practices in rice production which can simultaneously benefits to farm income. To achieve the objective, systematic review is applied. The main criterion to select articles for review is to include an indicator called Net Ecosystem Economic Benefit (NEEB). The indicator does not only concern farm profit but also takes environmental impact, in term of cost, into account. The selected articles are then extracted from ScienceDirect and Scopus.

From the search and selection, 13 full articles are reviewed and summarized. Farm practices can be broadly classified into 5 groups, which are tillage, straw management, fertilizer, animal farming integration, and others. Firstly, it is consensus among the related articles that no-tillage practice can reduce CH_4 emission and save cost. Thus, it can simultaneously reduce environmental impact and improve farm profit.

Secondly, the impact of straw management on NEEB is still inconclusive. However, there is a common finding that returning straw to the paddy field can increase CH_4 emission.

Next, many researches focus on fertilizer application, especially nitrogen fertilizer, and the scope of study is vast. From the systematic review, it is general that fertilizer, regardless of type, certainly increases greenhouse gas emission. Nitrogen fertilizer significantly increases N_2O emission, and if it is also organic fertilizer, more CH_4 will be emitted as well. Although fertilizer incurs more environmental cost, fertilizer is still recommended as a farm practice because it can increase rice yield. As its benefit in rice yield gain outweighs the environmental cost, the NEEB value, therefore, increases, indicating it to be the recommended farm practice. However, to further extent, there are more environmentally friendly fertilizer, but they turn out to be too expensive, causing farm profit to fall and unattractive to farmers. Those are controlled release fertilizer under plastic mulching cultivation and slow-release fertilizer. They can be served as examples that in order to implement more environmentally friendly practices, the balance between farm profit and environmental impact is necessary. The government may provide subsidies or price controls to these fertilizers, making them more profitable for farmers, as they also generate positive externality to the environment.

Another farm practice mentioned in the reviewed articles is rice-animal farming integration, including frogs, crabs, crayfish, and ducks. Their effects on greenhouse gas emission vary from a species to another. Most of the animal species, except crayfish, can increase rice yield. One of advantages from rice-animal integrations is that farm animal can be sold as an additional source of income, increasing NEEB value of the integrated farming. Comparing between 4 animal species, frogs and ducks may be more attractive alternatives than crayfish and crabs because integrated crayfish to rice cultivation results in lower rice yield and crabs results in higher greenhouse gas emission.

Lastly, there are also other farm practices which are plastic film mulching enhanced with urease and nitrification inhibitors (UNIs), rice-legume rotation, and biochar. Although plastic film mulching is proven to generate higher NEEB than traditional irrigation, and most types of UNIs can further decrease greenhouse gas emission, they are too expensive to be economically profitable. Likewise, biochar may have a potential for greenhouse gas mitigation. It is, however, found to be too expensive to be profitable for farm. Specifically, biochar may be actually economically feasible when applied to upland soil in a small amount as it can increase the yield, but it is relatively less effective for paddy soil which is the main soil type of rice cultivation in Thailand. Again, these are examples of how the government can intervene to control the prices of the products to be profitable for farmers in order to promote the use of them, and rice production will be more environmentally friendly. Although rice-legume rotation can help mitigating greenhouse gas emission by reducing the use of fertilizer, their grain yields still fluctuate and are uncertain, signaling the need of further researches to effectively balance between income and environmental impact.

In conclusion, from the study results for the second objective, no-tillage, application of nitrogen fertilizers, and integrated rice-animal farming, especially frogs and ducks, are recommended to be farm practices balancing between farm income and greenhouse gas mitigation. Additionally, a small amount of biochar application for rice cultivation in upland area may also be economically feasible. The government should implement policies to promote these types of farming practices. The starting point can be to share and publish this knowledge to Thai farmers nationwide. It is important to point out to them that these practices can not only help the environment but also to improve their incomes as well. The next step can be to provide subsidies as incentives for farmers to apply these farming practices. The criterion for subsidies can be based on the environmental indicator such as the amount of greenhouse gas emission per a hectare of rice field.

It is worth to note that some farm practices such as biochar in paddy soil and slow-release fertilizer may need government intervention policies for prices as they are more environmentally friendly but are too expensive to be profitable for farmers. For example, price ceiling policy can be implemented for slow-release fertilizer. In addition, the government can also invest in research and development for other farm practices such as rice-legume rotation and straw management to find out more about how they can balance benefits between economic and environmental aspects.

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