



Comparing Social Costs of the Conventional Rice Production System and System of Rice Intensification: A Case Study of Indonesia

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Abstract. The rice production process generated negative environmental externalities. These externalities were considered as a cost and not accounted by market price and the economic value of externalities was indefinite. The objective of this study was to calculate and internalize negative externalities costs into production costs of the System of Rice Intensification and conventional rice production system. The quantities of externalities measured in this research were CH₄, N₂O, SO₂, NO_x, and PM₁₀. This research used Life Cycle Analysis (LCA), damage cost approach, and social costs concept. This research was conducted at Dlingo Village in Boyolali District, Central Java Province. The results showed that the private cost per kg unhulled rice was 1,529 IDR and damage cost was 9 IDR/kg. Social costs of producing 1 kg unhulled rice was 1,539 IDR or 9.60 million IDR/ha/season. SRI's farmers received net social benefit 18.04 million IDR/ha/season. Considering that the target of extended area for SRI in 2015 was 200,000 ha, the government could receive environmental benefits 44.51 billion IDR. The benefits can be obtained through world carbon trading process and used as incentives for organic farmers.

Keywords. *negative externalities, social costs, conventional rice production system, SRI.*

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Introduction

Background

The System of Rice Intensification (SRI) has been implemented in many countries such as in Madagascar, Vietnam, Thailand, Cambodia, and Indonesia. Since the SRI method was first-time developed in Madagascar in 2001 by Henri Laulanie (Uphoof, 2015), this method was spread out and practiced in countries due to some benefits obtained by farmers. The benefits were reducing the amount of water, less chemical fertilizer use, decreasing seed use, increasing rice production, and as an environmentally friendly practice (FAO, 2002).

The SRI is different from conventional rice farming system. The SRI is stated by the Ministry of Agriculture Republic of Indonesia as the best solution for Indonesia's agriculture in increasing

rice production. The implementation of SRI is intended to boost the rice production by 1–2 tons rice per ha to achieve the national target of 10 million of rice production surplus (Ministry of Agriculture, 2014). The harvest time of SRI is shorter compared to the conventional system. The total amount of water used in conventional is twice as much water used in SRI. Avoiding the use of inorganic fertilizers and pesticides in SRI reduces the production cost (Ministry of Public Work, 2009).

Besides its benefits, agricultural practices also produce environmental externalities. The environmental externality is an environmental “free rider” that can impact on people. There are positive and negative environmental externalities. The negative environmental externalities are a cost. It is paid but not by farmers in the case of

rice production system, or by consumers (DeWitt, 1990). Most of the negative environmental externalities are not accounted by market price and the economic value of externalities is unknown (FAO, 2001; Lv et al., 2010).

A rice production system generates Green House Gases (GHGs), non-GHGs, and other substrates that have environmental impact categories resulted by both conventional rice production systems and SRI, namely global warming, acidification, and eutrophication (Blengini and Busto, 2009; Craighill and Powell, 1996; de Boer, 2003; Lv et al., 2010). There were studies related to the measurement of greenhouse gas emissions from rice fields. Most of these studies calculated the magnitude of methane (CH_4) and nitrous oxides (NO_x) (Dan et al., 2001; Huang et al., 2009; Johnson-Beebout et al., 2009; Kruger and Frenzel, 2003; Lindau, 1994; Neue, 1997; Sahrawat, 2004; Setyanto and Kartikawati, 2011; Setyanto et al., 2012; Wang et al., 1992; Wang et al., 1993; Wiharjaka, 2010; Wiharjaka et al., 2010).

Related to economic value, the concept of social costs that take into consideration externalities cost and internalize it into production cost, needs to be performed. Furthermore, rice farmers in Indonesia are considered to be easier to adopt a new system and technologies if economic benefits could be exhibited accompanying technical benefits. Economic benefits of practicing SRI should be delivered as policy advices to the Ministry of Agriculture in order to start to deeply consider the negative environment externalities in the conventional rice production system instead of focusing only on skyrocketing rice production with neglecting negative environmental impacts.

The objective of the study is to compare the social costs of the System of Rice Intensification (SRI) and conventional rice farming system for producing 1 kg unhulled rice. Within the context of the research objective, the following main research question is formulated: Are the social costs of producing 1 kg unhulled rice using SRI higher than those for conventional rice farming? Specifically, this research is carried out to answer the following sub research questions: (1) How much are the private production costs for

producing 1 kg unhulled rice using SRI and conventional rice farming?; (2) How high are the level and the damage costs of Green House Gases (GHGs) and non-GHGs emissions for producing 1 kg unhulled rice using SRI and conventional rice farming?; (3) How much are the social costs for producing 1 kg unhulled rice using SRI and conventional rice farming?

Research Framework

The interaction of the economy and the environment should not only be connected from economy to environment, but also associate from environment to economy. This two-sided interaction between economic and environment has a prime benefit that it could exhibit the optimal environmental policy calculation which shows the equal of marginal cost and marginal benefit of pollution abatement (Zhu, 2014).

In any economy, normally the more quantity and efficient of inputs use means the greater the amount of output. However, the production systems also create pollution in the form of air or water pollution and other liquid and solid wastes. These pollutions may have an impact on production and also the availability of the inputs that can be used in the production process. Furthermore, it can affect human health. Productivity will decrease, and economic cost will increase, due to higher health care allowance and decrease the amount of labor supply and labor productivity (Faber et al., 2002; Haites, 1990; Rennings and Wiggering, 1997).

Related to the connection of environment and economy or production, the Ministry of Agriculture of Indonesia has been implementing agricultural farming policies and has launched the System of Rice Intensification (SRI) program to boost rice production and to bridge agriculture and environment. The main differences between the SRI and the conventional rice production system that farmers commonly practiced are that the SRI uses less amounts of water, no chemical fertilizers are used in the entire system, and no chemical pesticide, insecticide and herbicide. In general, it can be said that SRI is closer to the organic rice farming system.

Although the SRI has been declared by the Ministry of Agriculture as an environmentally

friendly farming system, it should be assessed that this system has less negative environmental externalities compared to the conventional one because the negative externalities could harm the environment and impact on human and animal health. Social costs are calculated in order to know the benefit of a system while considering externalities in each production cost calculation. These assessment results can be used by agricultural extension agents in their counselling materials to support the Ministry of Agriculture's efforts to accelerate SRI dissemination.

The first step in this study is to calculate the production cost per functional unit of measurement for each conventional rice farming system and SRI. By using the Life Cycle Assessment (LCA) approach, this study examined fossil fuel and inputs use in the conventional rice production system and SRI, and externalities resulted from both systems. This technique could also be used to calculate environmental impacts into different categories. The environmental impacts were categorized into global warming impact, acidification and nitrification or eutrophication (Figure 1). Because the unit of measurement of each category was different, the damage cost approach was used to monetize the environmental externalities in order to generate externalities cost considering the damage cost of each rice production system. This means that the different units from each impact categories were calculated in the same unit of measurement because in LCA, there was an essential problem that environment impacts were measured in different units, or related to comparing two systems in this study, in noncomparable units (Craighill and Powell, 1996).

Finally, the social costs of the SRI and conventional rice production system that included production cost and damage cost, were calculated. Then, policy recommendations were proposed to the Ministry of Agriculture in order to accelerate the dissemination of the rice farming system which was more environmentally friendly.

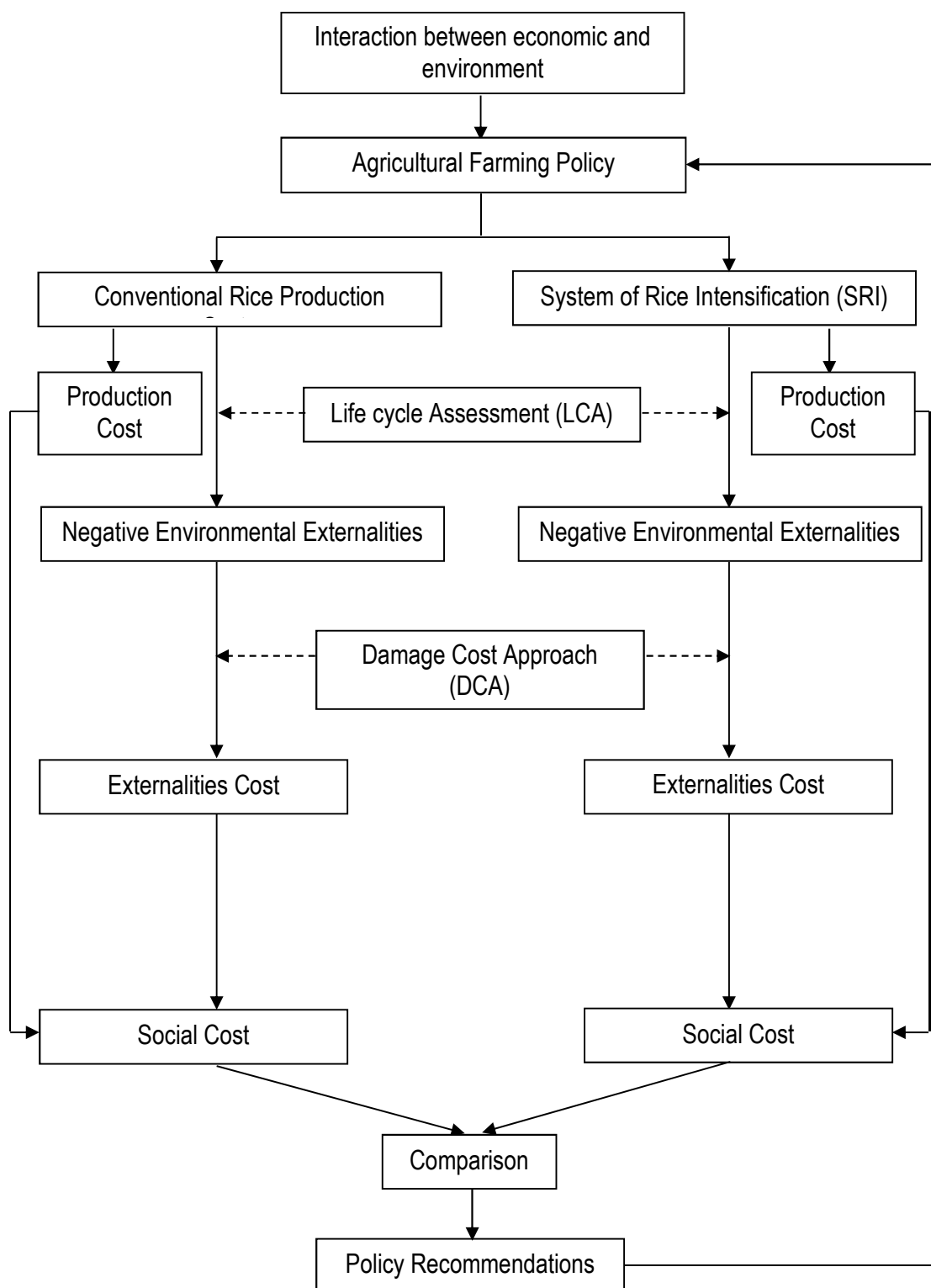
Methods of Data Collection and Study Site

To answer sub research question 1 (*How much is the production cost of 1 kg unhulled rice for each conventional rice farming system and SRI?*), inter-

views with SRI farmers and conventional farmers that were selected randomly on the study site, were carried out in order to collect input data and fuel use, and also unhulled rice production in the conventional rice farming system and SRI. In the study site, two wetland paddy areas were chosen for GHGs and non-GHGs analysis. One area was allocated for the SRI area (called SRI area), and another area with the same size was for conventional system (called conventional area). The SRI area was selected to be very close to two-neared springs and its location had terracing land contours, in order to avoid chemical matter contamination from the conventional area. The conventional area was chosen below the SRI area with flat land contour, and separated by a river.

In each area, one ha plot was selected for sample taking. In each plot, three points were chosen based on the same age of paddy, and if possible, with the same paddy variety. However, three plots consisted of a paddy field with different paddy variety planted. In the SRI area, three plots were planted by the same paddy variety, i.e. IR64. For the conventional area, three plots were cultivated by different paddy variety, i.e. Cihayang, Mekonga, and local variety. The sample of GHGs and non-GHGs were then taken from these three plots for each area by a researcher and assisted by two technicians.

For collecting input-output data from five farmer groups existed in the study site, two farmer groups were selected. These two farmer groups were the farmers cultivating paddy in the SRI and conventional area that were selected for GHGs and non-GHGs analysis. Fifty members of the 73 members of the first farmers group were then selected randomly to be respondents in this research, and 50 members of the 91 members of the second farmer group were also selected randomly. The 73 and 91 members' names were collected from each group of farmers and written down on a piece of paper. Each paper was then rolled up and inserted into a glass for each group. Fifty rolled papers were taken from each glass to be respondents in this research. A researcher, accompanied by one research assistant visited, one-by-one, each farmer to interview them using a questionnaire in terms of gathering input-output inventory.

**Figure 1:** Research Framework

For sub question 2 (*How high are the level and the damage costs of Green House Gases (GHGs) and non-GHGs emissions for producing 1 kg unhulled rice using SRI and conventional rice farming?*), this study applied the Life Cycle Assessment approach. This study performed field observation to gather primary data from the wetland rice farming area in study site. During field observations, GHGs samples were taken using the closed chamber method (Ariani et al. 2011; Husnain et al. 2014; Setyanto and Kartikawati, 2011) and analyzed in the laboratory by using the gas chromatography device. The GHGs samples were taken three times: firstly, when the age of paddy was 35 days after planting; secondly, 65 days after planting; and thirdly, 95 days after planting.

By using three chambers in each point in each plot at the same time, CH₄ and N₂O gas samples were accommodated. The size of the CH₄ chamber was 50 cm x 50 cm x 103 cm, whilst for the N₂O chamber, 40 cm x 20 cm x 15 cm. For CH₄, the samples in each point were taken 5 times with 5 minutes of intervals by using a syringe. Meanwhile, for N₂O, the samples were accepted 5 times with 10 minutes of intervals. The sample collection started at 6 a.m. It started on SRI plot for around 1 hour and continued to the conventional plot. The samples of CH₄ and N₂O gases were brought to the laboratory and analyzed by gas chromatography for around 1 week until the analyzing process was finished. Two laboratory assistants assisted the analyzing process in the laboratory.

Field observations were carried out in the October–March 2014/2015 paddy season. Literature studies about GHGs emission measurements were also carried out in order to complete measurement data and as a comparator data from other study sites that have been published. For non-GHGs, its emissions were calculated by using the quantity of inputs and gasoline data taken from interviews with farmers multiplied by emission factors. In addition, this study used published data about the coefficients that were used to transform the quantity of GHGs and non-GHGs emission into a homogenous unit. This study did not measure the damage costs directly from the field observation in order to determine

externalities cost, but using the published damage cost.

To answer sub question 3 (*How much are the social costs for producing 1 kg unhulled rice using SRI and conventional rice farming?*), the production cost of each conventional rice farming system and SRI, which are provided by the answer of sub question 1 and the externalities cost, obtained from the answer of sub research question 2, were summed up to exhibit the social costs for each SRI and conventional system.

This study selected Dlingo village in Boyolali District, because paddy farmers in some locations in Boyolali have followed SRI training, implemented SRI techniques, and during 2012–2013, the Boyolali Farmers Association received the International Market Ecology Organization (IMO) certificate. Their organic SRI rice production has also been exported to Belgium.

Data Analysis

After the number of inputs and diesel use were obtained, as part of the LCI, the quantity of pollutants discharged to the environment was calculated. The information of CH₄ and N₂O concentration taken from the study site were provided, and subsequently calculated flux and emissions of each pollutant. Furthermore, SO₂, NO_x, and PM₁₀ emissions were also accounted by using the amount of input use and emission factors for each input.

There were three steps in calculating CH₄ and N₂O emissions. Firstly, CH₄ and N₂O concentration were obtained from field observation by using the closed chamber method and analyzed by a gas chromatography device. Secondly, flux for each pollutant was calculated by using a formula explained in Equation 1. Thirdly, emissions of CH₄ and N₂O are estimated by using the emission estimated formula explained in Equation 2.

The CH₄ and N₂O's flux mean are the estimated numbers on how much gas is flowing out from paddy plants or land to air (Setyanto et al., 1999; Setyanto, 2012). The concentration rates of CH₄ and N₂O for C0-35, C36-65, and C66-95 categories are used in calculating flux. Subsequently, CH₄ and N₂O flux are calculated by using a formula (IAEA, 1993; Setyanto et al., 1999; Setyanto, 2004; 2012) as follows (Eq. 1):

$$F = \frac{dc}{dt} \times h \times \frac{mW}{mV} \times \left(\frac{273.2}{273.2+T} \right) \quad [1]$$

Notations in the formula are explained below:

F = flux of CH₄ and N₂O gas (mg/m²/day)

$\frac{dc}{dt}$ = difference in CH₄ and N₂O concentrations per time (ppm/minute)

h = height of the chamber (m)

mW = molecule weight of CH₄ and N₂O (mg)

mV = constant volume of CH₄ and N₂O molecule (m³)

T = average temperature during sampling (°C)

273.2 = a constant Kelvin temperature

Total CH₄ and N₂O gas emission in a season for SRI is calculated by using Equation 2. The amount of CH₄ and N₂O flux is used to estimate total CH₄ and N₂O emissions per ha in a season from three paddy growing phases by using the following formula (Setyanto, 2004):

$$E_{gas} = \frac{F_{0-35} + F_{36-65} + F_{66-95}}{Ls - N} \times (H - N) \times \left(\frac{10,000 \text{ m}^2}{1,000,000 \text{ kg}} \right) \quad [2]$$

E_{gas} = estimated gas emission (kg/ha/season)

F₀₋₃₅, F₃₆₋₆₅, F₆₆₋₉₅ = cumulative flux of 0–35, 35–65, and 66–95 days after planting

N = age of seed (days after planting)

Ls = last day sampling (days after planting)

H = age of paddy until harvesting

For calculating SO₂, NO_x, and PM₁₀ emissions, the quantity of gasoline, diesel, and chemical fertilizer used in farming activities was obtained from field observation in the study site. After the average consumption of gasoline and diesel per ha has been calculated, SO₂, NO_x, and PM₁₀ emissions were accounted by multiplying the average consumption of gasoline and diesel per ha by emission factors for each pollutant.

$E_{SO_2} = (Q_{diesel} * EF_{SO_2 \text{ for Diesel}}) + (Q_{gasoline} * EF_{SO_2 \text{ for gasoline}}) + (Q_{CheFert} * EF_{SO_2 \text{ for Chemical Fertilizer}})$

$E_{NO_x} = (Q_{diesel} * EF_{NO_x \text{ for Diesel}}) + (Q_{gasoline} * EF_{NO_x \text{ for gasoline}}) + (Q_{CheFert} * EF_{NO_x \text{ for Chemical Fertilizer}})$

$E_{PM_{10}} = (Q_{diesel} * EF_{PM_{10} \text{ for Diesel}}) + (Q_{gasoline} * EF_{PM_{10} \text{ for gasoline}}) + (Q_{CheFert} * EF_{PM_{10} \text{ for Chemical Fertilizer}})$

$$Enongas = E_{SO_2} + E_{NO_x} + E_{PM_{10}} \quad [3]$$

E_{SO₂}, E_{NO_x}, E_{PM₁₀} = emission for SO₂, NO_x, and PM₁₀

Q_{diesel}, Q_{gasoline}, Q_{CheFert} = the average consumption of gasoline, diesel and chemical fertilizer per ha.

EF = emission factors

By using the Global Warming Potential (GWP) concept supported by the Intergovernmental Panel on Climate Change (IPCC), the quantity of gaseous emission was transformed into carbon dioxide (CO₂) equivalent. The GWP is a concept that accounts the effect of gaseous emissions over the whole sphere and the changes of gaseous concentration over time. This study used a 100-year basis of the GWP concept to determine the carbon dioxide equivalent value of CO₂ for CH₄ and N₂O gases resulted from SRI practice.

The other gaseous emissions (SO₂, NO_x, and PM₁₀) are conveyed in terms of hydrogen ion mass equivalent by multiplying the quantity of SO₂, NO_x, and PM₁₀ emission with the coefficient of 31.3 for SO₂ and 21.7 for NO_x (Craighill and Powell, 1996). Due to the lack of coefficient data for PM₁₀, the quantity of PM₁₀ did not transfer into hydrogen ion mass equivalent. The sum of hydrogen ion mass equivalent is considered as the total environmental impact of acidification.

In this study, the availability of nitrogen oxides (NO_x) was measured. The quantity of these two emissions was transformed into a phosphate ion equivalent by using coefficient. The coefficient is 0.13, and it was multiplied by the quantity of NO_x (Craighill and Powell, 1996). The sum of the phosphate ion equivalent of NO_x was considered as eutrophication environmental impact.

Economic evaluation to estimate the value of each GHGs and non-GHGs emission in each rice production system was calculated by multiplying the quantity of each gas emission with the damage values for calculating the external costs. The damage costs estimation was obtained from

study literature and it was based on the condition in the UK. The damage cost for each pollutant were $\text{CO}_2 = 0.004 \text{ £/kg}$, $\text{CH}_4 = 0.072 \text{ £/kg}$ and $\text{N}_2\text{O} = 0.614 \text{ £/kg}$ (Craighill and Powell, 1996); $\text{SO}_2 = 2.58 \text{ £/kg}$, $\text{NO}_x = 1.27 \text{ £/kg}$, PM_{10} (particulates less than $10 \text{ }\mu\text{m}$ on diameter) = 8.98 £/kg (CEC, 1994).

These damage costs were converted into Indonesia's currency (IDR). The social cost was accounted by summing up the production cost and the damage cost (external cost) for SRI system. The social costs were calculated and then the social benefits were determined from implementing SRI. The results from LCA and economic evaluations were combined with information obtained from interview results descriptively to produce policy recommendation on how to deliver the economic benefits to the farmers implementing the SRI.

Input-Output Inventory

Input and labor costs

In this part, the explanations are delivered by comparing the technical instruction book of SRI implementation released by the Ministry of Agriculture with the results of field observation in

the study site. There are five types of input group explained in this part, i.e. seeds, organic fertilizers, chemical fertilizers, chemicals, and gasoline. The use of diesel for operating tractors was obtained from Simatupang et al. (2009). Inputs use per ha are shown in Table 1.

Input use in the conventional system was higher compared to the SRI, except for the use of organic fertilizer for the SRI (3,980 kg/ha), which was higher than the conventional system (876 kg/ha). The conventional system's input value was higher than the SRI's input value (Table 1). Most of the farmers practicing both farming systems did not buy the organic fertilizer. They used and processed cattle waste as organic fertilizer because the farmers grow cattle and the cattle waste was abundant.

Some farmers who did not have cattle or goats, but wanted to use cattle and goat manure, bought cattle or goat manure from their neighbors who had cattle or goats manure surplus. The average cattle manure price was 753 IDR/kg. Farmers also could buy organic fertilizer produced by a fertilizer factory in agricultural kiosks in the village, but they did not do it and preferred to use animal waste in order to minimize production cost.

Table 1

The use of inputs per ha on wetland paddy in Dlingo village, 2014-2015.

Type of input	SRI Unit	Vol	Price/Unit	Value	Conventional Vol	Price/Unit	Value
Seeds	kg	34	8,333	283,322	50	10,300	515,000
Organic Fertilizers	kg	3,980			876		
Chemical Fertilizers:							
N (Urea)	kg				259	2,271	588,243
P ₂ O ₅ (SP-36)	kg	1	2,200	2,200	263	2,200	578,810
K ₂ O (ZA)	kg				224	2,050	458,524
NPK	kg				193	2,700	522,132
Others	kg	1	3,000	3,000			
Chemicals	Rp						278,346
Gasoline	liter	15	7,500	109,500	21	7,833	162,926
Total				398,022			3,103,981

Source: primary, computed.

Table 2

Labor cost per ha on wetland paddy in Dlingo village, 2014-2015.

Type of activity	Source of Labor Sex		SRI Hours spent	Wage per hour	Total	Conventional Hours spent	Wage per hour	Total
Seed Breeding	Family	Female	1					
		Male	69			97		
	Outside Family	Female						
		Male	9	9,500	85,500			
	Total		79			97		
Tillage					1,364,064			1,188,639
Revocation and removal of seeds	Family	Female				11		
		Male	8			61		
	Outside Family	Female				6	10,000	60,000
		Male	34	10,889	370,226			
	Total		42			78		
Planting	Family	Female				53		
		Male						
	Outside Family	Female	104	9,079	944,216	94	9,375	881,250
		Male	18	10,750	193,500	18	8,750	157,500
	Total		122			165		
Waterways improvement	Family	Female						
		Male	59			178		
	Outside Family	Female						
		Male	222	10,194	2,263,068			
	Total		281			178		
Organic Fertilizer Application	Family	Female	23			5		
		Male	63			5		
	Outside Family	Female	34	8,750	297,500			
		Male	41	10,550	432,550			
	Total		161			10		
Inorganic Fertilizer Application	Family	Female				22		
		Male				41		
	Outside Family	Female						
		Male						
	Total		-			63		
Weeding	Family	Female	19			98		
		Male	96			160		
	Outside Family	Female	48	10,929	524,592	11	10,929	120,219
		Male	32	10,667	341,344	9	10,667	96,003
	Total		195			278		
Spraying	Family	Female						
		Male	20			43		
	Outside Family	Female	2	12,500	25,000			
		Male						
	Total		22			43		
Harvesting	Family	Female	17			27		
		Male	19			28		
	Outside Family	Female	76	9,219	700,644	50	9,821	491,050
		Male	99	10,421	1,031,679	70	10,393	727,510
	Total		211			175		
Total			1,113		8,573,883	1,087		3,722,171
All labors as cost			1,113	10,287	11,449,802	1,087	10,287	11,182,331

Source: primary, computed

The information about labor use is shown in Table 2. This research labor use into 10 farming activities, namely seed breeding, tillage, revocation and removal of seeds, planting, waterways improvement, organic fertilizer application, inorganic fertilizer application, weeding, spraying, and harvesting. The use of labor was provided in working hours. The maximum working hour per day was 8 hours. This information was divided by source of labor (family labor or outside family labor) and sex (male or female). This study assumed that family labors were not paid by farmers. The wage was the average wage for each farming activity per hour, and included meals and cigarettes given by farmers for each labor.

Total working hours per ha of SRI practice was 1,113 working hours, with the assumption that farmers produced unhulled rice and sold it to traders without further processing, such as drying or grading (Table 2). These working hours were very close to other research results, stating that effective working hours in Boyolali District were 1,277 working hours (Mahananto et al., 2009). The SRI system desired high working hours in waterways improvement, organic fertilizers application, and harvesting phases. The total labor cost was 8.57 million IDR/ha.

Other Costs

Other costs were defined as the costs that do not include input or labor costs such as land tax, bags for packing unhulled rice, needle and thread for tailoring bags, pumps because a few farmers used pumps for watering their paddy field, and others, to cover a small amount of costs during the farming process (Table 3). Land tax was imposed to each land that was used for growing paddy. The amount of land tax was different for each land depending on its location. If the land is fertile according to the village officials' survey and close to the village's main road, the land tax is more expensive and vice versa. The average land tax on SRI farmers was lower compared to conventional farmers because the locations of SRI farmers' land were near the natural spring and in terracing areas. In contrast, the conventional farmers' lands were in a flat location and near the irrigation canal and village main road.

Table 3

Other cost per ha on wetland paddy in Dlingo village, 2014-2015.

Type of other costs	Unit	SRI	Conventional
Land Tax	IDR	78,047	104,626
Bag	IDR	181,742	234,023
Needle and thread	IDR	28,731	57,572
Pump	IDR	124,636	===
Others	IDR	152,636	196,658
Total	IDR	565,792	592,879

Source: primary, computed.

The cost of bags, and needle and thread for the conventional system was higher because farmers bought new bags for each season. Meanwhile, pump cost was spent by SRI farmers because a few farmers' land locations needed to use a pump to siphon water due to their land location in terracing area.

Production and Benefit

The production of unhulled rice per ha for SRI was 6.24 tons/ha, and for the conventional system, 6.57 tons/ha. A minor difference of production between the SRI system and the conventional system ensued because most of the SRI farmers have implemented the SRI system since 2006. The paddy production will decrease in the first 2–3 years after farmers decide to alter their farming system from conventional to SRI or organic system. After 3 years of implementing SRI, the paddy production will increase until it is closer to conventional production (FAO, 2002; Mayrowani, 2013; Ministry of Public Works of Republic of Indonesia, 2009; Setyanto, 2004). However, according to the SRI farmers in this study, SRI paddy production has not ever surpassed the conventional paddy production.

The average price of unhulled rice per ha was also different between the SRI and conventional system. The price of SRI's unhulled rice was 4.433 IDR/kg, higher than the conventional unhulled rice production (4.333 IDR/kg). The higher price received by SRI farmers took place because SRI farmers have already had a "promise" from buyers (in this case, the buyer is Boyolali Farmers Alliance or APPOLI). The "promise" did not mean a written contract, but a deal between farmers and buyer that if the farmers

planted paddy with the same variety as the buyers wanted to buy in harvesting season, farmers will receive the higher price than the price implemented at the time farmers harvested. However, if SRI farmers did not sell their unhulled rice to APPOLI but to other buyers or to the open market, they will receive the same price as the conventional product or the price that applied at the time farmers sold their product.

Farmers' private revenue for each system was calculated by multiplying the average of price per kg with the average of total unhulled rice per ha. For SRI, farmers' private revenue was 27.64 million IDR/ha. Meanwhile, farmers' private revenue for the conventional system was 28.48 million IDR/ha. The slightly higher price of the conventional system private revenue occurred due to the higher yield (338 kg/ha) and minor difference of price (100 IDR/kg). The SRI farmers' benefit was 18.1 million IDR/ha and conventional farmers obtained 21.0 million IDR/ha.

The use of inputs and gasoline in the SRI and conventional system were higher than the standard stated in technical books or the Ministry of Agriculture's provision. In SRI, seed use was higher than the standard, meanwhile organic fertilizer

and gasoline use were still in the range of standard. In the conventional system, chemical fertilizer use is very high compared to the Ministry of Agriculture recommendation. In this case, farmers thought that by using more chemical fertilizers, paddy production will also increase.

All input prices obtained by farmers were higher compared to government's provision. Farmers received higher price because their paddy fields were far from the kiosks selling inputs so that delivering inputs need added costs. Besides, the input prices depend on the quality of the products and farmers had some choices relating to many kinds of brands of inputs sold in the kiosks. Farmers will pay different prices for each input.

Comparing SRI practices carried out by farmers and SRI practices in SRI technical books, there were some differences found in the study site. SRI farmers did not do seed breeding in a small container, instead carried it out in the field. There were also a few farmers who used chemical fertilizers for growing seeds. Farmers also did not plant one seed for each planted hole. However, most of the SRI practices were carried out by SRI farmers, except some minor differences.

Table 4

The concentration rate of CH₄ (ppm) and N₂O (ppb) per minute for SRI and Conventional System.

Pollutants	Concentration's category	SRI	Conventional
CH ₄	C0-35	0.0455 (0.0490)	0.8375 (0.1866)
	C36-65	0.0114 (0.0123)	0.2094 (0.0466)
	C66-95	0.0228 (0.0245)	0.4188 (0.0933)
N ₂ O	C0-35	0.0758 (0.0523)	3.9492 (2.6766)
	C36-65	0.0190 (0.0131)	0.9873 (0.6692)
	C66-95	0.0379 (0.0262)	1.97458 (1.3383)

Source: primary, computed. Note: figures in parenthesis are standard deviation. Data calculated by, for example, sampling at t, minus sampling at t-1, and carried out for all intervals, and then averaged per minute.

Table 5

Properties for calculating CH₄ and N₂O Flux for SRI and conventional system.

Items	Unit	SRI	Conventional
CH ₄ box's height	m	1.03	1.03
N ₂ O box's height	m	0.2	0.2
CH ₄ 's molecule weight	mg	16.12 x 10 ³	16.12 x 10 ³
N ₂ O's molecule weight	mg	44.01 x 10 ³	44.01 x 10 ³
Constant volume of CH ₄ and N ₂ O's molecule	m ³	22.41 x 10 ⁻³	22.41 x 10 ⁻³
Average temperature during sampling	Kelvin's degree	303.60	303.30

Source: primary, computed.

GHGs and Non-GHGs Emission

The Concentration of CH₄ and N₂O

To calculate CH₄ and N₂O fluxes, the rates of CH₄ and N₂O concentration were accounted first. The concentration of CH₄ was obtained from three points (three sample locations) in a 1 ha plot. The N₂O concentration was also gained from the same points. By taking gas samples for every 5 minutes until 25 minutes, the concentration of CH₄ was taken from each point. Meanwhile, for N₂O, a gas sample was taken for every 10 minutes until 50 minutes. The measurement of GHGs concentration is calculated in three categories, i.e. firstly, when the age of paddy was 35 days after planting (namely C0-35), secondly, the age of paddy was 65 days after planting (namely C36-65), and thirdly, when age of paddy was 95 days after planting (namely C66-95). The concentration of CH₄ and N₂O can be seen in Table 4.

The Properties for Calculating Flux

There are some properties that should be measured to calculate flux, i.e. the height of the CH₄ and N₂O chamber used in taking samples process, the weight of CH₄ and N₂O molecules, constant volume of CH₄ and N₂O's molecule, and average temperature during sampling. These properties are measured in order to determine all parameters needed in flux's formula in Equation 1.

The height of CH₄ and N₂O chambers were taken from the field. The CH₄ chamber was 103 cm or 1.03 m. Meanwhile, the height of the N₂O chamber was 20 cm or 0.2 m. The weight of the CH₄ and N₂O molecules were obtained from the literature (IAEA, 1993; Khalil et al., 1991; Setyanto,

2004). Constant volume of CH₄ and N₂O's molecules was obtained from Avogadro's Law stating that "the principle that equal volumes of all gases at the same time temperature and pressure contain the same number of molecules. Thus, the molar volume of all ideal gases at 0 °C and a pressure of 1 atm is 22.4 liters" or 22.41 x 10⁻³ m³ according to IAEA (1993). Average temperatures were obtained from field observation, and measured in the degree of Celsius. In the GHGs' flux calculation, the average temperature was converted to the degree of Kelvin. Table 5 shows all properties for calculating CH₄ and N₂O flux for SRI.

CH₄ and N₂O Flux

The flux of CH₄ and N₂O for each growing phase is shown in Table 6. The "F" notation in the table means flux and F0-35 refers to flux at the age of 0–35 days after planting, F36-65 is in flux at the age of 36–65 days after planting, and F66-95 means flux at the age of 66–95 days after planting.

The CH₄ and N₂O flux showed the lower results from other findings. Ly et al. (2013) showed that CH₄ flux in a paddy field in Cambodia was between 200 and 400 mg/m²/day and N₂O fluxes varied between 7 and -6 mg/m²/day. Ly et al. (2013) also revealed that CH₄ flux for SRI was higher than CH₄ flux for conventional rice farming system. The same results also exhibited by Setyanto and Kartikawati (2008), explained that the highest CH₄ flux in SRI in Pati District, Central Java Province in Indonesia, was only 455 mg/m²/day and for a conventional system, it could reach 633.8 mg/m²/day.

Table 6

The CH₄ and N₂O's flux in three growing phases (mg/m²/day).

Pollutants	Flux's category	SRI	Conventional
CH ₄	F0-35	43.4731	72.4551
	F36-65	10.8683	18.1138
	F66-95	21.7365	36.2276
N ₂ O	F0-35	0.6400	3.0181
	F36-65	0.1600	0.7545
	F66-95	0.3200	1.5091

Source: primary, computed.

Table 7

CH₄ and N₂O emission (kg/ha/season) and CO₂ equivalent for SRI and conventional system.

Type of GHGs	SRI Emission	CO ₂ Equivalent	Conventional Emission	CO ₂ Equivalent
CH ₄	18.900217	472.50	31.500298	787.51
N ₂ O	0.293390	87.43	1.3834587	412.27

Source: primary, computed.

Setyanto and Kartikawati (2008) also explained that the CH₄ flux in paddy field was increased in the beginning of days planted, decreased at 65 days and slightly increased on days before harvesting time. However, Towprayoon et al. (2005) outlined that average fluxes of CH₄ in a paddy field in the central plain of Thailand were only 140–218 mg/m²/day, or lower compared to Ly et al. (2013) and Setyanto and Kartikawati (2008) findings.

CH₄ and N₂O Emission

The estimation of CH₄ and N₂O emissions for SRI is shown in Table 7. The calculation of CO₂ equivalent was performed by multiplying the emission of each gas with a coefficient of Global Warming Potential (GWP) for each gas, which is 25 for CH₄ and 298 for N₂O (Craighill and Powell, 1996; Lv et al., 2010; Setyanto, 2004). After the CO₂ equivalent for both gases were determined, it can be understood that N₂O emission was higher than CH₄ emission.

The calculation of CH₄ emissions was lower compared to Setyanto and Kartikawati's (2008) findings, which was 60.73 ± 9.13 kg/ha/season. Khalil et al. (1998) outlined that methane emission reached its highest rate at 100 kg/ha/season around the time of flowering and dropped slowly to reach 10 kg/ha/season at harvest time. The

two most important factors to explain the volatilization of methane emission were soil temperature variations and fertilizer application. The higher GHGs emission of the conventional system drove higher impacts on the rising global temperature on earth and it might affect human health, animal and crop life, and ecosystems (Craighill and Powell, 1996; de Boer 2003; FAO, 2001; Lv et al., 2010; Scialabb and Hattam, 2002). Comparing the emission of GHGs pollutant between SRI and conventional practice showed that SRI emission is lower than conventional practice.

In SRI, intermittent water management is applied, having an impact on less water use in farming practice. By applying reducing water use in the paddy farming system, it will cut CH₄ emissions. Some research results exhibited that intermittent water management in SRI reduced soil population methanogens, bacteria synthesizing CH₄, and increased the methanotrophs population, aerobic bacteria that ingest CH₄ (Rajkishore et al., 2013; Uphoff, 2015).

Emission of SO₂, NO_x and PM₁₀

After calculating GHGs emission in the previous phase, this phase estimated non-GHGs emissions. Firstly, chemical fertilizers, gasoline, and diesel were considered as the sources of SO₂,

NO_x, and PM₁₀, or non-GHGs emissions. There were four kinds of chemical fertilizers, i.e. N, P₂O₅, K₂O, and NPK (contains 15% N, 15% P₂O₅, and 15% K₂O). The use of chemical fertilizers, gasoline, and diesel per kg unhulled rice produced were obtained from input-output analysis. Table 8 provides the use of chemical fertilizers (N, P₂O₅, K₂O, and NPK), gasoline, and diesel per kg unhulled rice produced.

Secondly, emission factors of SO₂, NO_x and PM₁₀, which were explained as numbers showing the estimation on how much emission of each unit non-GHGs (Haites, 1990; Le et al., 2013), were determined for each source of non-GHGs emissions. The emission factors were taken from the GREET database and have been applied by Le et al., (2013). The emission factors for calculating non-GHGs emissions are shown in Table 8.

Thirdly, SO₂, NO_x, and PM₁₀ emissions were calculated by multiplying the use of chemical fertilizers, gasoline, and diesel per kg unhulled rice produced and the emission factors. In this study, emissions from the production of chemical inputs, organic fertilizers, and other insignificant inputs were disregarded due to the lack of emission factors data. Information in Table 9 shows the amount of emission per kg for each type of non-GHGs. The estimation of H⁺ equivalent for each non-GHGs emission was calculated by multiplying each non-GHGs emission with coefficients of 31.3 for SO₂ and 21.7 for NO_x (Craighill and Powell, 1996). The results can be seen in Table 9. Comparing the emission of non-GHGs pollutant between SRI and conventional practice showed that SRI emission is lower than conventional practice.

Table 8

Chemical fertilizers, gasoline and diesel use per kg unhulled rice produced and emission factors of non-GHGs.

Sources of non-GHGs emission	The use of inputs per kg unhusked rice produced			Emission Factors			
	Unit	SRI	Conventional	Unit	SO ₂	NO _x	PM ₁₀
Chemical Fertilizers:							
N	kg	-	0.022454	g/kg	3.027600	4.664800	0.653600
P ₂ O ₅	kg	0.000160	0.007378	g/kg	7.379300	2.315200	0.852300
K ₂ O	kg	-	0.031756	g/kg	1.156200	1.482000	0.220300
NPK	kg	-	0.013793	g/kg	3.854367	2.820667	0.575400
Gasoline	MJ	0.077470	0.108450	g/MJ	0.013600	0.021800	0.002200
Diesel	MJ	0.103290	0.103290	g/MJ	0.013100	0.021400	0.002100

Sources: primary and Le et al. (2013), for emission factors, computed.

Table 9

SO₂, NO_x and PM₁₀ emission (kg/ha/season).

Type of non-GHGs	SRI Emission	H ⁺ Equivalent	Conventional Emission	H ⁺ Equivalent
SO ₂	0.0000036	0.0001123	0.0002151	0.0067337
NO _x	0.0000043	0.0000927	0.0002124	0.0046084
PM ₁₀	0.0000005	0.0000000	0.0000359	0.0000000

Source: primary, computed.

Table 10

Converting damage costs of GHGs and non-GHGs for the UK to damage costs for Indonesia

Pollutants	Damage cost for UK (£/kg) ¹	Adjusting factors ² GDP/cap ratio	Population density ratio	Damage cost for Indonesia (IDR/kg)
CH ₄	0.072	0.20299	0.44718	45.04
N ₂ O	0.614	0.20299	0.44718	384.115
SO ₂	2.584	0.20299	0.44718	1,616.54
NO _x	1.270	0.20299	0.44718	794.51
PM ₁₀	8.980	0.20299	0.44718	5,617.84

Source: ¹ Craighill and Powell (1996), computed; ² FAO and CBS of Indonesia, computed.

Note: Exchange rate used in converting damage costs is 6,891.85 IDR/£ (Source: Bank of Indonesia, average exchange rate in 2014, PPP).

Acidification is the discharging of emission of gasses into the air and when mixed with other molecules in the atmosphere resulting in acidification of ecosystems (Craighill and Powell, 1996; de Boer, 2003). The higher the emissions of SO₂, NO_x and PM₁₀ calculated in this study meant the increase of aluminum concentration in ground water and affected the growth of root of crops, and at the end, increased the potential of crop damage because of diseases and drought. Increasing the concentration of aluminum in ground water will be toxic to human and animal life.

Surface water nitrification, also known as eutrophication, is an added emission of substrates and gasses to the surface water and air that boost the growth pattern of ecosystems. Nitrogen nitrification will agitate the balance of nutrient composition in soil that can lead to the increase the vegetation composition into abundant nitrogen loving species. Enhancing the level of nitrogen in nitrate form into the groundwater consumed by humans will cause oxygen deficiency in human blood, particularly for children. The higher NO_x emission (NO_x in phosphorus ion equivalent was calculated by multiplying coefficient of 0.13 with the amount of NO_x emission, equals to 5.6E-07 kg/ha/season for SRI and 2.76E-05 kg/ha/season for conventional) meant the higher phosphorus eutrophication that increases the growth of algae and plants and when they die, the microbial degradation will decrease the amount of oxygen in the water, decreasing the capacity of water to maintain life (de Boer, 2003).

Damage Cost

Due to the lack of damage costs of GHGs and non-GHGs data in Indonesia, this study applied proxies for damage costs. This research used damage costs in the UK from Craighill and Powell (1996) and adjusted the damage costs for Indonesia. This study applied the same method that Le et al., (2013) performed, which used gross domestic product (GDP) per capita and population density as two adjusting factors based on the assumption that the difference between the UK and Indonesia, regarding willingness to pay and physical damage per kg pollutant as two foundations in calculating damage costs, could be reflected by these two adjusting factors. The ratios of GDP per capita (PPP) and population density between the UK and Indonesia were used as two adjusting factors. Damage costs for UK multiplied by adjusting factors were calculated to exhibit damage costs for Indonesia (Table 10).

Total damage costs of each pollutant for SRI and conventional system were calculated by multiplying damage costs for Indonesia from Table 10, with CH₄ and N₂O emission stated in Table 7 for GHGs, and SO₂, NO_x, and PM₁₀ emissions showed in Table 9 for non-GHGs. Total damage costs for SRI and the conventional system are counted by adding up the damage cost from each pollutant. Total damage costs are measured per kg unhulled rice and per ha paddy field (Table 11). Comparing the damage costs of GHGs pollutants and non-GHGs pollutant between SRI and conventional practice showed that conventional damage cost was higher than conventional practice.

Table 11

Total damage cost per kg unhulled rice and per ha paddy field for SRI and conventional system.

Pollutants	SRI (IDR/kg)	Conventional	SRI (IDR/ha)	Conventional
CH ₄	3	5	21,283	33,583
N ₂ O	6	24	35,471	150,359
GHGs	9	29	56,754	183,942
SO ₂	0.18	10.89	1,132	71,549
NO ₂	0.07	3.66	459	24,066
PM ₁₀	0.00	0.20	18	1,342
Non-GHGs	0.26	14.75	1,609	96,958
Total (GHGs + Non-GHGs)	9	44	58,363	280,899

Source: primary, computed.

Table 12

Private cost, damage cost and social cost of System of Rice Intensification and conventional rice production system.

Items	SRI (IDR/kg)	(IDR/ha)	Conventional (IDR/kg)	(IDR/ha)
Private cost	1,529.70	9,537,697	1,128.71	7,419,031
Damage (external) cost	9	58,363	44	280,899
% damage cost to private cost	0.59	0.61	3.90	3.79
Social cost (No. 1) + (No. 2)	1,539	9,596,060	1,173	7,699,930
Revenue	4,433	27,639,755	4,333	28,480,809
Benefit:				
Net Private Benefit (No. 5) – (No.1)	2,903	18,102,058	3,204	21,061,778
Net Social Benefit (No. 5) – (No. 4)	2,894	18,043,695	3,162	20,780,879

Source: primary, computed.

Social Costs

This section provides the calculation of social costs by internalizing the damage costs. Social costs for SRI were calculated by adding up private cost and damage costs. Social costs were measured for per kg unhulled rice and per ha paddy field. Private costs per kg unhulled rice were calculated by adding up input costs, labor costs, and other costs, and dividing by total unhulled rice production. Private cost per kg was 1,529 IDR/kg unhulled rice (Table 12).

In calculating SRI's private cost, this research showed that labor cost (its share of total production cost was 70%) and organic fertilizer costs (16%) became two important calculations due to its highest share. In the Dlingo Village case, almost all SRI farmers had cattle and/or goats, and used cattle waste and goat waste as organic fertilizers. A few SRI farmers also used compost as

organic fertilizer. SRI farmers did not have to buy the organic fertilizer because the amount of organic fertilizer was abundant. SRI farmers used 3,980 kg organic fertilizer per ha. By using the average of organic fertilizer price 753 IDR/kg, private cost for SRI increased 2.99 million IDR/ha (31.4% of total private cost), if organic fertilizer is considered as a cost. Meanwhile, real labor costs ("real" refers to input-output data taken from the study site, without adding some adjustments or scenarios) for SRI was 8.57 million IDR/ha/season.

Farmers who implemented the organic production system or SRI had lower damage cost, i.e. 9 IDR/kg unhulled rice. Calculating per ha, the amount of damage cost will be important to be considered because if the farmers deliberated to change the rice production method from the conventional system to SRI, farmers are estimated to reduce damage cost 35 IDR/kg unhulled rice or

80% of the conventional system's damage cost. Although the percentage of damage cost to private cost was only 0.59–3.90%, if damage cost was multiplied by the paddy area in Indonesia, the amount will be significant. The social cost per kg unhulled rice of SRI was 1,539 IDR/kg unhulled rice. Due to the higher the amount of SRI private cost compared to conventional private cost, although social costs have been internalized into private cost, net private benefit, and net social benefit of practicing SRI were lower compared to conventional practice (Table 12).

Discussion

There are many factors influencing GHGs measurement. Wang et al. (1993), outlined that the methane flux measurement in some rice field areas in China differs significantly from the methane emissions pattern and amount in other areas. Methane emission fluxes exhibited diurnal variations throughout the entire paddy growing season for the early paddy, which is the paddy planted and harvested in 90–100 days, and the late rice, which is the paddy harvested in 100–120 days. Wang's findings showed that methane emission is estimated 17×10^{12} g/(m²*year). However, methane emission reached 16.2 g/(m²*year) for early rice and 75.9 g/(m²*year) in 3 years research in Leshan (1988–1990), and 7.8 g/(m²*year) for early rice and 28.6 g/(m²*year) for late rice in Hangzhou. These findings are also supported by Setyanto (2004) and Setyanto et al. (2012) revealed that different paddy varieties will be one of the reasons researchers found the different amounts of methane emission.

Besides, local climate, soil types, and paddy growing activities are another important factor in measuring emission rates (Dan et al., 2001; Setyanto and Kartikawati, 2008; Setyanto et al., 2012; Wang et al., 1993). By comparing year to year emission data in 1988–1989, the methane emissions showed the difference of flux patterns because the temperature is different during the period of measurement. Soil and air temperature also could make a different on methane measurement. The chemical fertilizer application is also a major factor impacted on the different

measurement of methane emission because fertilization caused the enhancement of paddy growth due to additional substrate that consequence of the increasing of methane production.

At the time GHGs were measured in the field, the in situ measurements were also important factor. The time of the sample taking process determined the results. In the morning, the methane emission rate is higher than in the afternoon. If the research objective is to compare such as SRI and the conventional system, the sample taken from the two areas must be at the same time or if there is a time difference, it would be within a very short period.

The findings mentioned above indicate the complex nature of the factors governing the measurement of GHGs can influence the research results. In this case, a researcher should be cautious in calculating the total seasonal emission. Because there are many factors influencing the GHGs emission measurement, another research could be carried out in order to enrich the various findings of GHGs measurement in different climatic condition, paddy variety, locations, and measurement methods.

In calculating damage costs, this research used damage cost for each pollutant and used damage costs data published by Craighill and Powell (1996) in the UK. Some literatures have calculated the social costs converting each pollutant into CO₂, H⁺ and phosphate equivalent, and then used the damage cost published data that accounted the damage cost for each CO₂, H⁺ and phosphate equivalent (Nordhaus, 2011; Pretty et al., 2000). In present research, the total damage cost is calculated by using the damage cost for each pollutant, not the damage cost for each CO₂, H⁺ and phosphate equivalent. Calculating the total damage costs by using different damage costs techniques will produce the different results. This means all monetary estimates are subject to varying degrees of uncertainty, depending on various methods use. For larger research, calculating the damage cost directly in the field would be an advantage to enrich published data about damage costs.

Conclusions and Policy Recommendations

Production cost of 1 kg unhulled rice by applying System of Rice Intensification was 1,529 IDR/kg or 9.54 million IDR/ha/season. By implementing the SRI system in producing 1 kg unhulled rice, farmers could reduce the quantity of CH₄ emission from 31.5kg/ha/season to 18.94 kg/ha/season or decreased 40%. N₂O emission could also be decreased by transferring their conventional farming practice to SRI from 1.383 kg/ha/season to 0.293 kg/ha/season or decreased 78.8%. In line with GHGs emission, the quantity of SO₂, NO_x, and PM₁₀ emission in producing 1 kg unhulled rice were also diminished by implementing SRI system. By implementing the SRI system, it produced 0.0000036, 0.0000043, and 0.0000005 kg/ha/season, correspondingly.

The damage cost of CH₄ and N₂O emission in producing 1 kg unhulled rice by applying SRI were 3 IDR/kg and 6 IDR/kg, respectively. Damage cost of SO₂, NO_x, and PM₁₀ produced by SRI system was relatively very low. The damage cost of SO₂, NO_x, and PM₁₀ were 0.18, 0.07, and 0.00 IDR/kg unhulled rice, respectively. Total damage cost of GHGs and non-GHGs of producing 1 kg unhulled rice by applying SRI was 9 IDR/kg unhulled rice. Converting to 1 ha, the total damage cost of practicing SRI was 58,363 IDR/ha/season. The social cost of producing 1 kg unhulled rice by implementing SRI was 1,539 IDR/kg unhulled rice.

In summary, the social cost calculation in this research proved that there is much economic benefit if farmers intend to transfer their rice production practice from conventional to SRI, even though the economic benefits are intangible. The government could take these advantages by using carbon trading mechanism. By using the SRI extended area in 2015, as much as 200,000 ha, the government could receive 222,536 IDR per ha or 44.51 billion IDR/200,000 ha. This estimated economic benefit can be used by the government to improve farmers' welfare or to support organic farming system in Indonesia such as

providing added input subsidies for SRI farmers, improving the village road for easing and lowering rice transaction cost, or even providing a price subsidy. Besides, the government could facilitate SRI farmers for producing premium rice since SRI method based on organic practice. All those on benefits can be chosen by the government to enhance the SRI method and the area through its counseling programs.

This research only uses 100 farmers for collecting input-output data and considers a very small number of samples. If the number of samples is increased, the findings would be different. This research also only had three points of observation and performed three times sample taking for GHGs emissions in a season, which were categorized as a small number of samples. This research was performed in a village as a study site, and the findings in this research cannot be used as an estimation of a larger area situation, in Indonesia as an example.

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