EXTERNALITIES INCLUSION INTO PRODUCTION COST OF SYSTEM OF RICE INTENSIFICATION

Memperhitungkan Eksternalitas ke Biaya Produksi Usaha Tani System of Rice Intensification

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ABSTRACT

Rice production process generates negative environmental externalities. These externalities are considered as a cost and not accounted by market price such that its economic externalities value is unknown. This study aims to calculate and to internalize negative externalities costs into production costs of the System of Rice Intensification as a rice production process based on organic practices. The quantities of externalities measured in this research are CH₄, N₂O, SO₂, NOₓ, and PM₁₀. This research uses a Life Cycle Analysis (LCA), a damage cost approach, and a social costs concept. This research was conducted in Dlingo Village, Boyolali Regency, Central Java Province. The results show that the private cost per kg of unhulled rice was Rp1,529 and damage cost per kg of unhulled rice was Rp1,539 or Rp9.60 juta/ha/musim. Keuntungan bersih setelah memasukkan biaya eksternalitas yang diperoleh petani SRI mencapai Rp18.04 juta/ha/musim. Dengan menggunakan target perluasan wilayah SRI pada tahun 2015 sebesar 200,000 ha, maka pemerintah dapat memperoleh keuntungan Rp44.51 miliar.

Keywords: System of Rice Intensification, Life Cycle Analysis, penggabungan, nilai eksternalitas, biaya sosial

INTRODUCTION

One of the programs in agricultural farming policy that has been disseminated by the Ministry of Agriculture is the System of Rice Intensification (SRI) (Ministry of Agriculture 2014). The System of Rice Intensification is considered to be a more environmentally friendly agricultural practice compared to the conventional rice farming system since SRI is based on organic practices. Further, the organic agriculture concept is based on methods used that respectful environment in all production phases and distributing system to the consumers. Practically, the organic agriculture is referred to minimize external inputs use and avoid chemical or synthetic fertilizer and pesticides. Even though, organic agricultural product is considered not to entirely free of residues related to the general environment pollution. The organic rice production is not only distressed with the product, but also concerned with whole agribusiness rice system (Sciallabb and Hattam 2002).

Agriculture produces environmental externalities. The environmental externality is an environmental "free rider" that can impact on
people. There are positive and negative environmental externalities, but in this research, our focus is only for negative 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. 2009).

Green House Gases (GHGs), non-GHG, and other substrates that have environmental impact categories resulted by both conventional rice production systems and SRI, are some examples of negative externalities (Craighill and Powell 1996; de Boer 2003; Lv et al. 2009; Blengini and Busto 2009). The negative environmental impacts are categorized into global warming impact, acidification, and nitrification or eutrophication. 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 acidification pollutants meant the increase of aluminum concentration in ground water and it affected the growth of root of crops, and at the end increased the potential of crop damage because of diseases and drought. The increasing concentration of aluminum in ground water will be toxic to human and animal’s life. Nitrogen nitrification will agitate the balance of nutrient composition in soil that can lead to the increase in vegetation composition into abundant nitrogen loving species. Enhancing the level of nitrogen in nitrate form into the groundwater consumed by human will cause oxygen deficiency in human blood particularly for children. Higher phosphorus eutrophication increases the growth of algae and plants and when they die, the microbial degradation will decrease the amount of oxygen in the water that decreasing the capacity of water to maintain life (de Boer 2003).

In economics, negative environmental externalities are real costs. They are considered to be very important and should not be ignored (DeWitt 1990). Therefore, government must have some policies or plans to anticipate the environmental damage impacting on the society’s daily life. Hence, raising society’s awareness on reducing the impact of negative environmental externalities by monetizing the quantity of externalities is important. There are plentiful studies related to the measurement of greenhouse gas emissions from rice fields. Most of these studies calculated the magnitude of methane (CH₄) and nitrous oxides (N₂O) (Wang 1993; Lindau 1994; Neue 1997; Dan et al. 2001; Kruger and Frenzel 2003; Sahrawat 2004; Huang et al. 2009; Johnson-Beebout et al. 2009; Setyanto and Kartikawati 2011; Setyanto et al. 2012).

Related to economic value, the concept of social costs that take into consideration externalities cost and internalize into production cost, needs to be performed. Rice farmers are easier to understand the benefits of implementing SRI if environmental impact assessments of SRI should be presented in economic value (Chernick and Caverhill 1990). Economic benefits of practicing SRI should be delivered as policy advice 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 was to calculate the inclusion of the externalities costs into production costs of the SRI for producing 1 kg unhulled rice. Within the context of the research objective, the following main research question was formulated: How much are the social costs of producing 1 kg unhulled rice using SRI compared with conventional practice? Specifically, this research was 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 system? (2) How high are the level and the damage cost of Green House Gases (GHGs) and non-GHG emissions for producing 1 kg unhulled rice using SRI? (3) How much is the social cost of producing 1 kg unhulled rice using SRI?

**RESEARCH METHODS**

**Conceptual Framework**

The framework begins with the interaction of the economy and the environment that should not only be connected from economy to environment, but also associated 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 input 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 inputs that can be used in production process. Furthermore, it can affect on 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 (Haites 1990; Rennings and Wiggering 1997; Farber et al. 2002).

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

Although the SRI is declared by the Ministry of Agriculture as an organic system, it should be assessed that this system has less negative environmental externalities compared to conventional one because the negative externalities could harm the environment and impact on human and animal health. Social costs were calculated in order to know the weaknesses and benefit of a system while considering externalities in production cost calculation.

The first step in this study was to calculate the production cost per functional unit of measurement for SRI. By using Life Cycle Assessment (LCA) approach, this study, then examines fossil fuel and inputs use in the SRI, and externalities resulted (Figure 1). Because the unit of measurement of each pollutant was different, the damage cost approach was used to monetize the environmental externalities in order to generate externalities cost. This means, the different units of the quantity of externalities are calculated in the same unit of measurement because in LCA, there is an essential problem that environment impacts are measured in different units, or in non-comparable units (Craighill and Powell 1996).

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

Life Cycle Assessment

Life cycle assessment is an approach that examines the environmental performance of a product, begins from assembling raw material from the earth to generate products and ends with returning all materials to the earth. LCA assesses throughout a product life cycle and accumulates environmental impacts creating from each stage of product life cycle. Technically, this technique can evaluate environmental aspects and impacts of gathering energy and material inputs released by a product life cycle, assessing potential environmental impacts from material inputs and discharges, interpreting the results to assist policy-makers in making decisions (SAIC 2006).
In its development and usage, LCA is used not only for collecting raw materials and inputs, and improving the environmental impacts of a product, but also for comparing the environmental impact of different products or systems (Craighill and Powell 1996; de Boer 2003). Life Cycle Assessment is a systematic approach and encompasses four main stages, namely the goal definition and scoping, life cycle inventory (LCI), life cycle impact assessment (LCIA) and interpreting the results (SAIC 2006). The goal definition and scoping phase explains the objectives, scope, and boundaries of two rice production systems, the functional unit, assumptions, and limitations in this research. The purpose of performing an LCA is to calculate the production of 1 kg unhulled rice by implementing SRI. The results of this LCA are used to support the expansion of the SRI dissemination that the Ministry of Agriculture of Republic of Indonesia has been carrying out to the date. The data used in this study are obtained by performing a case study for LCI and also the published data related to the production process.

The life cycle of SRI is exhibited in Figure 2. Preferably, an LCA examined the environmental impacts in all stages of the life cycle of a product. However, related to the study that calculated the social costs of SRI, this LCA only assessed environmental externalities from production machines and transportation use, driving energy such as gasoline (mentioned as energy use), and production processes relevant to produce 1 kg of unhulled rice.

This ‘cradle to farm gate’ flowchart (Harjanto et al. 2012), excluded the production process of seeds, insecticide, pesticide, herbicide, fertilizer, machines and buildings. Functional unit represents a unit of environmental impact measurement on rice production system. The functional unit is defined in terms of impact category and the objectives of the study. The functional unit is one kg of unhulled rice.

Life Cycle Inventory (LCI) is a process that produces a list of quantities of pollutants discharged to environment, material, and energy use. Life cycle inventory is performed as a basis
to assess comparative environmental impacts or potential improvement. There are four steps in conducting a life cycle inventory, namely building a flowchart of production system, setting a data collection plan, compiling data, and evaluating reporting results (SAIC 2006). A flowchart of rice production system (Figure 2) is developed to show inputs use and output resulted in SRI. Material and energy use, and also category of environmental discharge from both systems are explained. In both systems, this study assumes that there are no co-products.

In calculating the quantity of externalities in SRI, gaseous emissions from production practices, transport stages of bringing inputs and distributing output, the use of gasoline and diesel for operating tractors, cars, motorcycles and threshers are calculated because it has a contribution to environmental impacts. Life Cycle Impact Assessment (LCIA) is not performed in this research.

Damage Cost Approach

There are two approaches that can be performed to estimate the social costs from environmental impacts. Firstly, an approach based on prevention costs and secondly, approach based on estimated damages (Haites 1990). Haites (1990) added that the first approach is based on the proxy of prevention measures for the amount of society’s willingness to pay not to have the environmental impacts. The second approach is using the damage estimation, in this research, implementing rice farming systems and social costs should reflect this damage. This study used the damage cost approach by internalizing external cost into the whole production cost of SRI in order to analyze how much the net social benefit farmers could receive.

Damage cost approach is about to monetize environmental externalities, which presents an estimation of external cost. The environmental externalities is then stated as a cost per unit of externality, for instance, as Rp/kg of emissions or Rp/MJ or Rp/kWh of energy consumed (Rp = Indonesian Rupiah) (Chernick and Caverhill 1990).

Damage cost approach is carried out to monetize the damages resulted by discharging gaseous and non-gaseous emissions. This study drives an approximation of externalities costs of producing 1 kg unhulled rice. The damage cost of each externality was multiplied by the physical parameter to generate externalities value from each type of pollutants. In this research, pollutants scrutinized are CH₄ and N₂O for GHGs due to its highest emission released from paddy field (Khalil et al. 1991; Wang et al. 1992; Lindau 1994; Neue 1994; Dan et al. 2001; Kruger and Frenzel 2003; Setyanto 2004; Setyanto and Kartikawati 2008; Johnson-Beebout et al. 2009; Wihardjaka et al. 2010; Wihardjaka 2010; Ariani et al. 2011; Setyanto et al. 2012), and SO₂, NOₓ, and PM₁₀ for non-GHGs (Sahrawat 2004; Lv et al. 2010; Husnain et al. 2014). The social cost was calculated by summing up the production cost and the damage cost of various externalities.

Data Collection

To answer sub research question 1, interview with 50 SRI farmers that selected randomly on the study site, were carried out in order to collect input data and fuel use, and also unhulled rice production. Meanwhile, for conventional practice as a comparison, this research used study of literature. After Dlingo Village in Boyolali Regency, Central Java Province was determined, an area in Dlingo Village was chosen for GHGs and non-GHGs analysis. SRI area was selected to be very close to two-near springs and its location has terracing land contours, in order to avoid chemical matter contamination from conventional area.

In the area, one hectare plot was selected for sample taking. In each plot, three points were chosen based on the same age of paddy and paddy variety. However, three plots consisted of paddy field, and planted by the same paddy variety, i.e. IR64. 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 Dlingo Village, one farmer group was selected. The farmer group was the farmers cultivating paddy in the area that selected for GHGs and non-GHs analysis as mentioned before. 50 members of the 73 members of farmer group were then selected randomly to be respondents in this research. Researcher, accompanied by one research assistant, visited farmers one by one to be interviewed by using a questionnaire in terms of gathering input-output inventory.

For sub question 2, this study applied Life Cycle Assessment approach. This study performed field observation to gather primary data from wetland rice farming area in Dlingo Village in Boyolali Regency, Central Java Province. During field observation, GHGs
samples were taken by using the closed chamber method (Setyanto and Kartikawati, 2011; Ariani et al. 2011; Husnain et al. 2014) 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 was 65 days after planting; and thirdly was 95 days after planting.

By using three chambers in each point in each plot at the same time, CH$_4$ and N$_2$O gas samples were accommodated. The size of CH$_4$ chamber was 50 cm × 50 cm × 103 cm, whilst for N$_2$O chamber was 40 cm × 20 cm × 15 cm. For CH$_4$, the samples in each point were taken 5 times with 5 minutes of intervals by using a syringe. Meanwhile, for N$_2$O, the samples were accepted 5 times with 10 minutes of intervals. The sample collection started at 6 a.m. The samples of CH$_4$ and N$_2$O gases were brought to the laboratory and analyzed by gas chromatography. Field observations were carried out during October–March 2014/2015 paddy season.

For non-GHGs, its emissions are calculated by using the quantity of inputs and gasoline data taken from interview with farmers, multiplied by emission factors. In addition, this study used published data about the coefficient that were used to transform the quantity of GHGs and non-GHGs emission into 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, the production cost of each conventional rice farming system and SRI, which provided by the answer of sub question 1 and the externalities cost, which obtained from the answer of sub research question 2, were summed up to exhibit the social costs. Finally, policy advices were performed in order to accelerate SRI dissemination.

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

**Data Analysis**

After the number of inputs and gasoline use were obtained, as part of the LCI, the quantity of pollutants discharged to the environment was calculated. The information of CH$_4$ and N$_2$O concentration taken from the study site were provided, and subsequently calculated flux and emissions of each pollutant. Furthermore, SO$_2$, NO$_x$, and PM$_{10}$ emissions were also accounted by using the amount of input use and emission factors for each input.

There were 3 steps in calculating CH$_4$ and N$_2$O emission. Firstly, CH$_4$ and N$_2$O concentration were obtained from field observation by using the closed chamber method and analyzed by gas chromatography device. Second, flux for each pollutant was calculated by using a formula explained in Eq. 1. Thirdly, emission of CH$_4$ and N$_2$O are estimated by using emission estimated formula explained in Eq. 2.

The CH$_4$ and N$_2$O’s flux mean the estimated numbers on how much gas flowing out from paddy plants or land to air (Setyanto et al. 1999; Setyanto 2014). The concentration rates of CH$_4$ and N$_2$O for C0–35, C36–65, and C66–95 categories are used in calculating flux. Subsequently, CH$_4$ and N$_2$O flux are calculated by using a formula (IAEA 1993; Setyanto et al. 1999; Setyanto 2004; Setyanto 2014) as follows (Eq. 1):

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

Notations in the formula are explained below:

- $F$ = flux of CH$_4$ and N$_2$O gas (mg/m$^2$/day)
- $\frac{dc}{dt}$ = difference in CH$_4$ and N$_2$O concentrations per time (ppm/minute)
- $h$ = height of the chamber (m)
- $mW$ = molecule weight of CH$_4$ and N$_2$O (mg)
- $mV$ = constant volume of CH$_4$ and N$_2$O molecule (m$^3$)
- $T$ = average temperature during sampling ($^\circ$C)
- 273.2 = a constant Kelvin temperature

Total CH$_4$ and N$_2$O gas emission in a season for SRI is calculated by using a formula explained below. The amount of CH$_4$ and N$_2$O flux is used to estimate total CH$_4$ and N$_2$O emissions per ha in a season from three paddy growing phases by using the following formula (Setyanto 2004) (Eq. 2):

$$E_{\text{gas}} = \frac{F_0 - 35 + F_{36} - 65 + F_{66} - 95}{Ls - N} \times (H - N) \times \left(10,000 \times \frac{m^2}{1,000,000 \text{ kg}}\right) \quad \text{ (2)}$$
Egas = 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

By using Global Warming Potential (GWP) concept supported by the Intergovernmental Panel on Climate Change (IPCC), the quantity of gaseous emission is 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, NOₓ, and PM₁₀) are conveyed in terms of hydrogen ion mass equivalent by multiplying the quantity of SO₂, NOₓ, and PM₁₀ emission with the coefficient of 31.3 for SO₂ and 21.7 for NOₓ (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.

Economic evaluation to estimate the value of each GHGs and non-GHG 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 CO₂ = £0.004/kg, CH₄ = £0.072/kg and N₂O = £0.614/kg (Craighill and Powell 1996); SO₂ = £2.58/kg, NOₓ = £1.27/kg, PM₁₀ (particulates less than 10 µm on diameter) = £8.98/kg (CEC 1994).

These damage costs were converted into Indonesia's currency (Rp). In this research, the damage costs have already accounted for each pollutant, so each pollutant is not necessary to convert to CO₂ and hydrogen equivalent. 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.

RESULTS AND DISCUSSION

Input–Output Inventory

In this part, the explanations are delivered by comparing the technical instruction book of SRI implementation released by Ministry of Agriculture of Indonesia, and training of trainer book issued by VECO Indonesia, with the results of field observation in Dlingo Village. VECO Indonesia is an NGO that dedicated its activities to develop organic rice farming, especially in Boyolali Regency. 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.

Some farmers who did not have cattle or goats, but wanted to use cattle and goat manure, must bought cattle or goat manure from their neighbors who had cattle or goats manure surplus (Table 2). The average cattle manure price was Rp753/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.

The information about labor use was shown in 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 labors was provided in working hours. 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 including 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 unhusked rice and sold it to trader without further processing such as drying or grading (Table 3). These working hours were very close to other research result which stated that effective working hours in Boyolali Regency 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 Rp8.57 million/ha.
Other Costs

Other costs were defined as the costs that were not included in input or labor costs such as land tax, bag for packing unhulled rice, needle and thread for tailoring bag, pump because a few farmers used pump for watering their paddy field, and others, to cover small amount costs during the farming process (Table 4). Land tax was imposed to each land that used for growing paddy. The amount of land tax was different for each land depends 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 costs of bag, needle, and thread for conventional system were high 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. The spread of other costs data was high, especially for pumping cost and other production costs. Table 4 showed each item of the other costs data.

Production and Benefit

The production of unhulled rice per ha for SRI was 6.24 tonnes/ha, while for the common rice production system, or conventional rice production system, was 6.57 tonnes/ha (for conventional system, data taken from Maulana [2015]). Minor difference of production between SRI system and a conventional system ensued because most of SRI farmers have implemented SRI system since 2006. The paddy production will decrease in the first 2–3 years after farmers decided 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 close to conventional production (Sciallabb and Hattam 2002; Setyanto 2004; Ministry of Public Works of Republic of Indonesia 2009; Mayrowani 2013). Although SRI farmers in this study informed that SRI paddy production has not ever surpassed the conventional paddy production, some research results showed different information revealing that paddy production increased while farmers implement SRI method compared to conventional system (Uphoff 2005; Kabir and Uphoff 2007; Sharif 2011; Cornell Chronicle 2013; Uphoff 2015).

The average price of unhulled rice per ha was also different between SRI and conventional system. The price of SRI’s unhulled rice was Rp4,433/kg, higher than conventional unhulled rice production (Rp4,333/kg, Maulana [2015]). 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 Organic Farmers Alliance or APPOLI).

### Table 1. The use of inputs per ha on wetland paddy in Dlingo Village, 2015

<table>
<thead>
<tr>
<th>No.</th>
<th>Type of input</th>
<th>SRI</th>
<th>Unit</th>
<th>Volume</th>
<th>Price/unit</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>1.</td>
<td>Seeds</td>
<td>SRI</td>
<td>kg</td>
<td>34</td>
<td>8,333</td>
<td>283,322</td>
</tr>
<tr>
<td>2.</td>
<td>Organic Fertilizers</td>
<td>SRI</td>
<td>kg</td>
<td>3,980</td>
<td></td>
<td></td>
</tr>
<tr>
<td>3.</td>
<td>Chemical Fertilizers:</td>
<td>SRI</td>
<td>kg</td>
<td>1</td>
<td>2,200</td>
<td>2,200</td>
</tr>
<tr>
<td></td>
<td>N (Urea)</td>
<td>SRI</td>
<td>kg</td>
<td>1</td>
<td>2,200</td>
<td>2,200</td>
</tr>
<tr>
<td></td>
<td>P2O5 (SP-36)</td>
<td>SRI</td>
<td>kg</td>
<td>1</td>
<td>2,200</td>
<td>2,200</td>
</tr>
<tr>
<td></td>
<td>K2O (ZA)</td>
<td>SRI</td>
<td>kg</td>
<td>1</td>
<td>2,200</td>
<td>2,200</td>
</tr>
<tr>
<td></td>
<td>NPK</td>
<td>SRI</td>
<td>kg</td>
<td>1</td>
<td>2,200</td>
<td>2,200</td>
</tr>
<tr>
<td></td>
<td>Others</td>
<td>SRI</td>
<td>kg</td>
<td>1</td>
<td>2,200</td>
<td>2,200</td>
</tr>
<tr>
<td>4.</td>
<td>Chemicals</td>
<td>SRI</td>
<td>Rp</td>
<td></td>
<td>3,000</td>
<td>3,000</td>
</tr>
<tr>
<td>5.</td>
<td>Gasoline</td>
<td>SRI</td>
<td>liter</td>
<td>15</td>
<td>7,500</td>
<td>109,500</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>398,022</td>
</tr>
</tbody>
</table>

Source: Primary data (2015), computed.

### Table 2. The average number of cattle and goats nurtured by each farmer in Dlingo Village, 2014 (head)

<table>
<thead>
<tr>
<th>No.</th>
<th>Types of livestock</th>
<th>SRI</th>
<th>Average</th>
<th>Min–max value</th>
<th>Standard deviation</th>
</tr>
</thead>
<tbody>
<tr>
<td>1.</td>
<td>Cattle</td>
<td>SRI</td>
<td>1.64</td>
<td>0–8</td>
<td>2.292</td>
</tr>
<tr>
<td>2.</td>
<td>Goats</td>
<td>SRI</td>
<td>2.10</td>
<td>0–8</td>
<td>3.048</td>
</tr>
</tbody>
</table>

Source: Primary data (2015), computed.
The ‘promise’ did not mean a written contract, but a deal between farmers and buyer that if farmers planted paddy with the same variety as the buyers wanted to buy in harvesting season, farmers will receive 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 open market, they will receive the same price as conventional product or the price that applied at the time farmers sold their product.

Farmers’ private revenue was calculated by multiplying the average of price per kg with the average of total unhulled rice per ha. Farmer’s private revenue was Rp27.64 million/ha/season,
Table 4. Other costs per ha on wetland paddy in Dlingo Village, 2015

<table>
<thead>
<tr>
<th>No.</th>
<th>Type of other costs</th>
<th>Unit</th>
<th>SRI</th>
<th>Conventional</th>
</tr>
</thead>
<tbody>
<tr>
<td>1.</td>
<td>Land tax</td>
<td>Rp</td>
<td>78,047</td>
<td>104,626</td>
</tr>
<tr>
<td>2.</td>
<td>Bag</td>
<td>Rp</td>
<td>181,742</td>
<td>234,023</td>
</tr>
<tr>
<td>3.</td>
<td>Needle and thread</td>
<td>Rp</td>
<td>28,731</td>
<td>57,572</td>
</tr>
<tr>
<td>4.</td>
<td>Pump</td>
<td>Rp</td>
<td>124,636</td>
<td>=</td>
</tr>
<tr>
<td>5.</td>
<td>Others</td>
<td>Rp</td>
<td>152,636</td>
<td>196,658</td>
</tr>
<tr>
<td></td>
<td><strong>Total</strong></td>
<td><strong>Rp</strong></td>
<td><strong>565,792</strong></td>
<td><strong>592,879</strong></td>
</tr>
</tbody>
</table>

Source: Primary data (2015), computed

while farmers’ benefit was Rp18.1 million/ha/season.

GHGs and non-GHGs Emission

Concentration of CH₄ and N₂O

To calculate CH₄ and N₂O fluxes, the rate 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 concentration of N₂O 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, 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 paddy was 95 days after planting (namely C66-95). The concentration rate of CH₄ and N₂O can be seen in Table 5.

Properties for Calculating Flux

There are some properties that should be measured to calculate flux, i.e. the height of CH₄ and N₂O chamber used in taking sample 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 Eq 1.

The height of CH₄ and N₂O chambers were taken from the field. CH₄ chamber was 103 cm or 1.03 m. Meanwhile, the height of N₂O chamber was 20 cm or 0.2 m. The weight of CH₄ and N₂O molecules were obtained from the literature (Khalil et al. 1991; IAEA 1993; 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 × 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 6 showed all properties for calculating CH₄ and N₂O flux for SRI.

CH₄ and N₂O Flux

The flux of CH₄ and N₂O for each growing phase was shown in Table 7. 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.

Table 5. The concentration rate of CH₄ (ppm) and N₂O (ppb) per minute for SRI in Dlingo Village, 2015

<table>
<thead>
<tr>
<th>Pollutants</th>
<th>Concentration's category</th>
<th>SRI (ppm)</th>
<th>0.0455 (0.0490)</th>
</tr>
</thead>
<tbody>
<tr>
<td>CH₄</td>
<td>C0-35</td>
<td>0.0114</td>
<td>(0.0123)</td>
</tr>
<tr>
<td></td>
<td>C36-65</td>
<td>0.0114</td>
<td>(0.0123)</td>
</tr>
<tr>
<td></td>
<td>C66-95</td>
<td>0.0228</td>
<td>(0.0245)</td>
</tr>
<tr>
<td>N₂O</td>
<td>C0-35</td>
<td>0.0758</td>
<td>(0.0523)</td>
</tr>
<tr>
<td></td>
<td>C36-65</td>
<td>0.0190</td>
<td>(0.0131)</td>
</tr>
<tr>
<td></td>
<td>C66-95</td>
<td>0.0379</td>
<td>(0.0262)</td>
</tr>
</tbody>
</table>

Source: Primary data (2015), computed.
Note: Figures in parenthesis are standard deviation.

Data are calculated by, for example, sampling at t, minus sampling at t-1, and carried out for all intervals, and then averaged per minute.
The CH$_4$ and N$_2$O flux showed the lower results from other findings. Ly et al. (2013) showed that CH$_4$ flux in a paddy field in Cambodia was between 200 and 400 mg/m$^3$/day and N$_2$O fluxes varied between 7 and -6 mg/m$^3$/day. Ly et al. (2013) also revealed that CH$_4$ flux for SRI was higher than CH$_4$ flux for conventional rice farming system. The same results also exhibited by Setyanto and Kartikawati (2008), explained that the highest CH$_4$ flux in SRI in Pati Regency, Central Java Province in Indonesia, was only 455 mg/m$^3$/day and for a conventional system, it could reach 633.8 mg/m$^3$/day. Setyanto and Kartikawati (2008) also explained that the CH$_4$ 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 CH$_4$ in a paddy field in the central plain of Thailand were only 140–218 mg/m$^3$/day, or lower compared to Ly et al. (2013) and Setyanto and Kartikawati (2008) findings.

**CH$_4$ and N$_2$O Emission**

The estimation of CH$_4$ and N$_2$O emissions for SRI was shown in Table 8. The calculation of CO$_2$ 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 CH$_4$ and 298 for N$_2$O (Craighill and Powell 1996; Setyanto 2004; Lv et al. 2010). After CO$_2$ equivalent for both gases were determined, it can be understood that N$_2$O emission was higher than CH$_4$ emission (Table 8).

The calculation of CH$_4$ emissions was lower compared to Setyanto and Kartikawati (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 conventional system drove higher impacts on rising global temperature on earth and it might affect human health, animal and crop life, and ecosystems (Craighill and Powell 1996; FAO 2001; Sciallabb and Hattam 2002; de Boer 2003; Lv et al. 2010). 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 paddy farming system, it will cut CH₄ emissions. Some research results exhibited that intermittent water management in SRI reduced soil population methanogens which is bacteria synthesizing CH₄ and increased methanotrophs population that is aerobic bacteria that ingest CH₄ (Rajkishore et al. 2013; Uphoff 2015).

**Emission of SO₂, NOₓ, and PM₁₀**

After calculating GHGs emission in the previous phase, this phase estimated non-GHG emissions. Firstly, chemical fertilizers, gasoline, and diesel were considered as the sources of SO₂, NOₓ, and PM₁₀, or non-GHG emissions. There were four kinds of chemical fertilizers, i.e. N, P₂O₅, K₂O, and NPK (contain 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 9 provides the use of chemical fertilizers (N, P₂O₅, K₂O, and NPK), gasoline, and diesel per kg unhulled rice produced.

Secondly, emission factors of SO₂, NOₓ, and PM₁₀, which were explained as numbers showing the estimation on how much emission of each unit non-GHG emissions (Haites 1990; Le et al. 2013), were determined for each source of non-GHG emissions. The emission factors were taken from GREET database and have ever been applied by Le et al. 2013. The emission factors for calculating non-GHG emissions were shown in Table 9.

Thirdly, SO₂, NOₓ, 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 10 showed the amount of emission per kg for each type of non-GHG. 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 NOₓ (Craighill and Powell 1996). The results can be seen in Table 10. Comparing the emission of non-GHG pollutant between SRI and conventional practice showed that SRI emission is lower than conventional practice.

**Damage Cost**

Due to the lack of damage costs of GHGs and non-GHG 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 as Le et al. (2013) performed that 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. It is shown in Table 11.

Total damage costs of each pollutant for SRI and conventional system were calculated by multiplying damage costs for Indonesia from Table 11, with CH₄ and N₂O emission stated in Table 9 for GHGs, and SO₂, NOₓ, and PM₁₀ emissions showed in Table 10 for non-GHG. Total damage costs for SRI and conventional system are counted by adding up the damage cost from each pollutant. Total damage costs are

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**Table 9. Chemical fertilizers, gasoline, and diesel use per kg unhulled rice produced and emission factors of non-GHG in Dlingo Village, 2015**

<table>
<thead>
<tr>
<th>No.</th>
<th>Sources of non-GHG emissions</th>
<th>The use of inputs per kg unhulled rice produced</th>
<th>Emission factors</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>Unit</td>
<td>SRI</td>
</tr>
<tr>
<td>1.</td>
<td>Chemical fertilizers:</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>N</td>
<td>kg</td>
<td>-</td>
</tr>
<tr>
<td></td>
<td>P₂O₅</td>
<td>kg</td>
<td>0.000160</td>
</tr>
<tr>
<td></td>
<td>K₂O</td>
<td>kg</td>
<td>-</td>
</tr>
<tr>
<td></td>
<td>NPK</td>
<td>kg</td>
<td>-</td>
</tr>
<tr>
<td>2.</td>
<td>Gasoline</td>
<td>MJ</td>
<td>0.077470</td>
</tr>
<tr>
<td>3.</td>
<td>Diesel</td>
<td>MJ</td>
<td>0.103290</td>
</tr>
</tbody>
</table>

Sources: Primary data (2015) and Le et al. (2013), for emission factors, computed.
measured on per kg unhulled rice and per ha paddy field (Table 12). 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.

Social Costs

This chapter provided 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 divided by total unhulled rice production. Private cost per kg was Rp1,529/kg unhulled rice (Table 13).

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 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

---

Table 10. \( \text{SO}_2, \text{NO}_x, \text{and PM}_{10} \) emission (kg/ha/season)

<table>
<thead>
<tr>
<th>Type of non-GHGs</th>
<th>SRI</th>
<th>Conventional*</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Emission</td>
<td>H* equivalent</td>
</tr>
<tr>
<td>( \text{SO}_2 )</td>
<td>0.00000036</td>
<td>0.0001123</td>
</tr>
<tr>
<td>( \text{NO}_x )</td>
<td>0.0000043</td>
<td>0.0000927</td>
</tr>
<tr>
<td>( \text{PM}_{10} )</td>
<td>0.0000005</td>
<td>0.0000000</td>
</tr>
</tbody>
</table>

Source: Primary data (2015), computed.
Note: *Emission of non-GHGs for conventional system was obtained from Maulana (2015).

Table 11. Converting damage costs of GHGs and non-GHGs for the UK to damage costs for Indonesia

<table>
<thead>
<tr>
<th>No.</th>
<th>Pollutants</th>
<th>Damage cost for UK (£/kg)</th>
<th>Adjusting factors ²</th>
<th>Damage cost for Indonesia (Rp/kg)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1.</td>
<td>CH(_4)</td>
<td>0.072</td>
<td>0.20299 0.44718</td>
<td>45.04</td>
</tr>
<tr>
<td>2.</td>
<td>N(_2)O</td>
<td>0.614</td>
<td>0.20299 0.44718</td>
<td>384.115</td>
</tr>
<tr>
<td>3.</td>
<td>SO(_2)</td>
<td>2.584</td>
<td>0.20299 0.44718</td>
<td>1,616.54</td>
</tr>
<tr>
<td>4.</td>
<td>NO(_x)</td>
<td>1.270</td>
<td>0.20299 0.44718</td>
<td>794.51</td>
</tr>
<tr>
<td>5.</td>
<td>PM(_{10})</td>
<td>8.980</td>
<td>0.20299 0.44718</td>
<td>5,617.84</td>
</tr>
</tbody>
</table>

Source: ¹Craighill and Powell (1996), computed; ²FAO and CBS of Indonesia, computed.
Note: Exchange rate used in converting damage costs is Rp6,891.85/£1 (Source: Bank of Indonesia, average exchange rate in 2014, PPP).

Table 12. Total damage cost per kg unhulled rice and per ha paddy field for SRI and conventional system in Dlingo Village, 2015

<table>
<thead>
<tr>
<th>Pollutants</th>
<th>SRI (Rp/kg)</th>
<th>Conventional** (Rp/kg)</th>
<th>SRI (Rp/ha)</th>
<th>Conventional** (Rp/ha)</th>
</tr>
</thead>
<tbody>
<tr>
<td>CH(_4)</td>
<td>3</td>
<td>5</td>
<td>21,283</td>
<td>33,583</td>
</tr>
<tr>
<td>N(_2)O</td>
<td>6</td>
<td>24</td>
<td>35,471</td>
<td>150,359</td>
</tr>
<tr>
<td>GHGs</td>
<td>9</td>
<td>29</td>
<td>56,754</td>
<td>183,942</td>
</tr>
<tr>
<td>SO(_2)</td>
<td>0.18</td>
<td>10.89</td>
<td>1,132</td>
<td>71,549</td>
</tr>
<tr>
<td>NO(_x)</td>
<td>0.07</td>
<td>3.66</td>
<td>459</td>
<td>24,066</td>
</tr>
<tr>
<td>PM(_{10})</td>
<td>0.00</td>
<td>0.20</td>
<td>18</td>
<td>1,342</td>
</tr>
<tr>
<td>Non-GHGs</td>
<td>0.26</td>
<td>14.75</td>
<td>1,609</td>
<td>96,958</td>
</tr>
<tr>
<td>Total (GHGs + Non-GHGs)</td>
<td>9</td>
<td>44</td>
<td>58,363</td>
<td>280,899</td>
</tr>
</tbody>
</table>

Source: Primary data (2015), computed.
Note: **Damage costs for conventional system were obtained from Maulana (2015).
used 3,980 kg organic fertilizer per ha. By using the average of organic fertilizer price Rp753/kg, private cost for SRI increased Rp2.99 million/ha (31.4%), 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 Rp8.57 million/ha/season.

Farmers who implemented organic production system or SRI had lower damage cost, i.e. Rp9/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 conventional system to SRI, farmers are estimated to reduce damage cost Rp35/kg of conventional unhulled rice or 80% of the conventional system’s damage cost (Maulana 2015). 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 of SRI unhulled rice of SRI was Rp1,539/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 13).

### CONCLUSION AND RECOMMENDATION

Production cost of 1 kg unhulled rice by applying System of Rice Intensification was Rp1,529/kg or Rp9.54 million/ha/season. By implementing the SRI system in producing 1 kg unhulled rice, farmers could reduce the quantity of CH₄ emission from 31.5 kg/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, NOx, and PM₁₀ emission in producing 1 kg unhulled rice were also diminished by implementing SRI system. By implementing the SRI system produced 0.00000036, 0.00000043, and 0.00000005 kg/ha/season, correspondingly.

Damage cost of CH₄ and N₂O emission in producing 1 kg unhulled rice by applying SRI were Rp3/kg and Rp6/kg, respectively. Damage cost of SO₂, NOx, and PM₁₀ produced by SRI system was relatively very low. The damage cost of SO₂, NOx, and PM₁₀ were Rp0.18, Rp0.07, and Rp0.00 per kg unhulled rice, respectively. Total damage cost of GHGs and non-GHGs of producing 1 kg unhulled rice by applying SRI was Rp9/kg unhulled rice. Converting to 1 ha, the total damage cost of practicing SRI was Rp58,363/ha/season. The social cost of producing 1 kg unhulled rice by implementing SRI was Rp1,539/kg unhulled rice.

In summary, the social cost calculation in this research proved that there was 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 Rp222,536 per ha or Rp44.51 billion per 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 SRI method and the area through its counseling programs.

This research only uses 50 farmers for collecting input-output data and consider as 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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