CHAPTER 7
COMPARISON OF UTILIZATION OF UNUSED RESIDUE

7.1 Introduction

Pollutants and GHG emissions from rice residue open burning is a problem. A way to solve this problem is to manage the unused residue by utilization.

Rice residue has a high potential for energy purpose and agricultural purpose. It can be transformed to energy product as electricity, fuel, and so on. It is also use as nutrient for soil. To get the highest benefit from the management of unused residue, it needs to assess the possible residue management method.

The objective of this part is to compare GHG emissions from different utilization of unused rice field residue that would be leads to the optimized method of unused residue management to reduce emission from rice residue open burning.

7.2 Methodology

The utilization of unused residue is proposed for avoiding emission from open burning. This study focuses on 2 purposes of utilization; agricultural purpose and energy purpose. The optimum utilization of unused rice residue is in term of at least carbon dioxide equivalent and possibility of implementation. This study developed 3 scenarios and compare emission of 3 scenarios with emission from base line. The summary of base line and 2 scenarios is shows in Table 7.1.

Base line

Base line is the actual pattern in Thailand: rice residue is burned in the field; unburned residue is incorporated into the soil; coal/lignite for heat or power production. Base line emission includes emission from open burning of unused residue (E_1), emission from rice cultivation in the burned area due to incorporate residue after burned into the soil (E_2), and emission from 1,609 MW power productions by coal/lignite in thermal power plant (E_3). (1,609 MW is the median value of the range of maximum potential of unused rice straw; information of potential of unused straw for power production is shown in chapter 6). See Figure 7.1 for structure of base line.

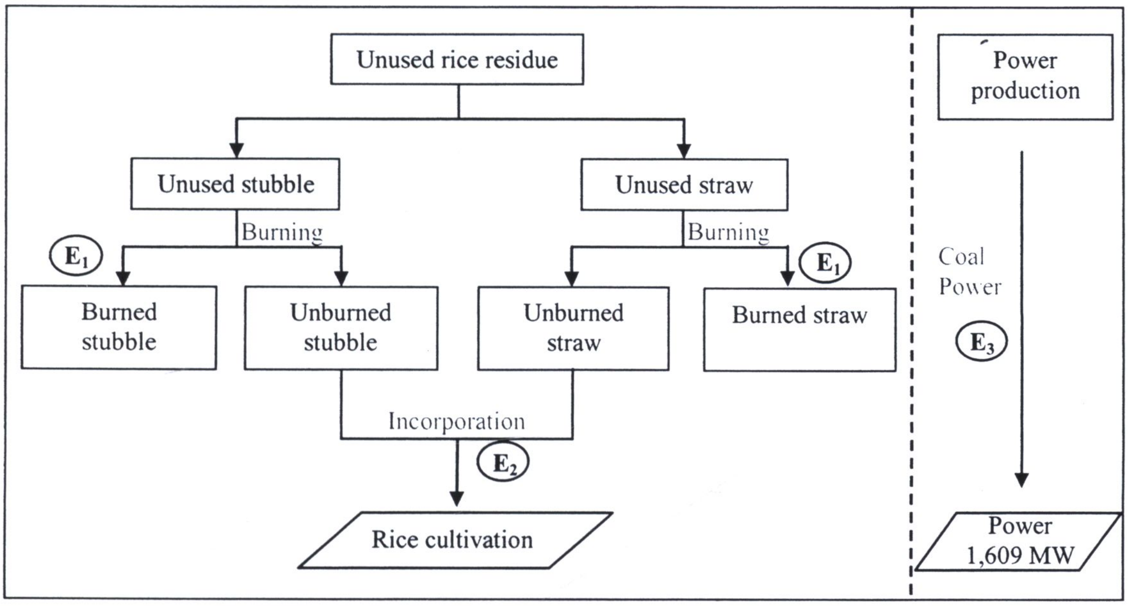

Figure 7.1 Structure of base line

Scenario 1: Zero open burning by agricultural purpose

This scenario assumes all of unused residue is incorporated into the soil. Scenario 1s' emission includes (1) emissions from rice cultivation that unused residue is incorporated into the soil (E_1) and (2) emission from 1,609 MW power productions by coal/lignite in thermal power plant (E_2). See Figure 7.2 for structure of Scenario 1.

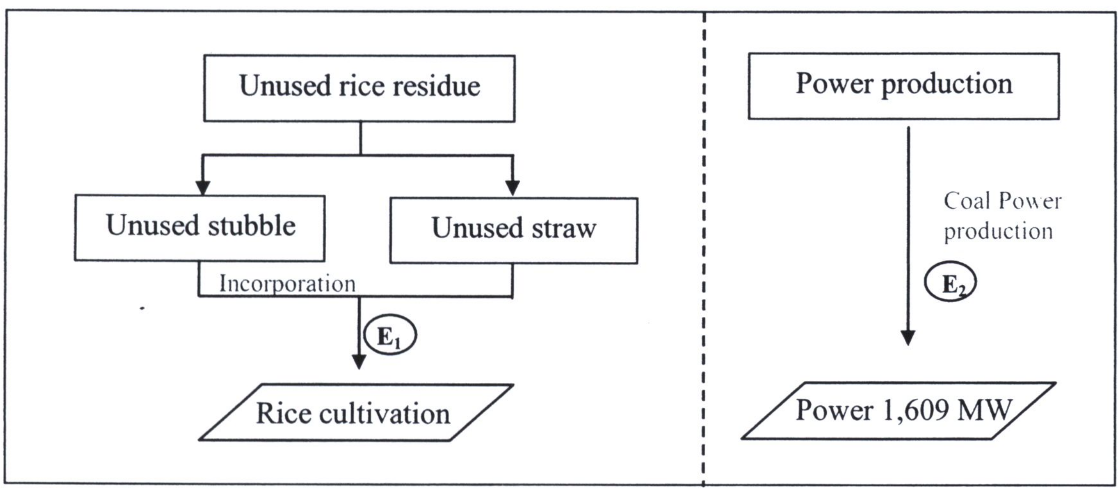

Figure 7.2 Structure of Scenario 1

Scenario 2: Zero open burning by energy purpose

This scenario assumes all of unused residue is used for heat and power production. The unused residue that can be used for heat or power production is only unused straw. The unused stubble does not use heat or power production because of too much difficult for implementation. The unused stubble is incorporated into the soil. Scenario 2's emissions includes (1) emissions from rice cultivation in the burned area due to incorporate unused stubble into the soil (E_1) and (2) emissions from 1,609 MW power productions by unused straw in thermal power plant (E_2). See Figure 7.3 for structure of Scenario 2.

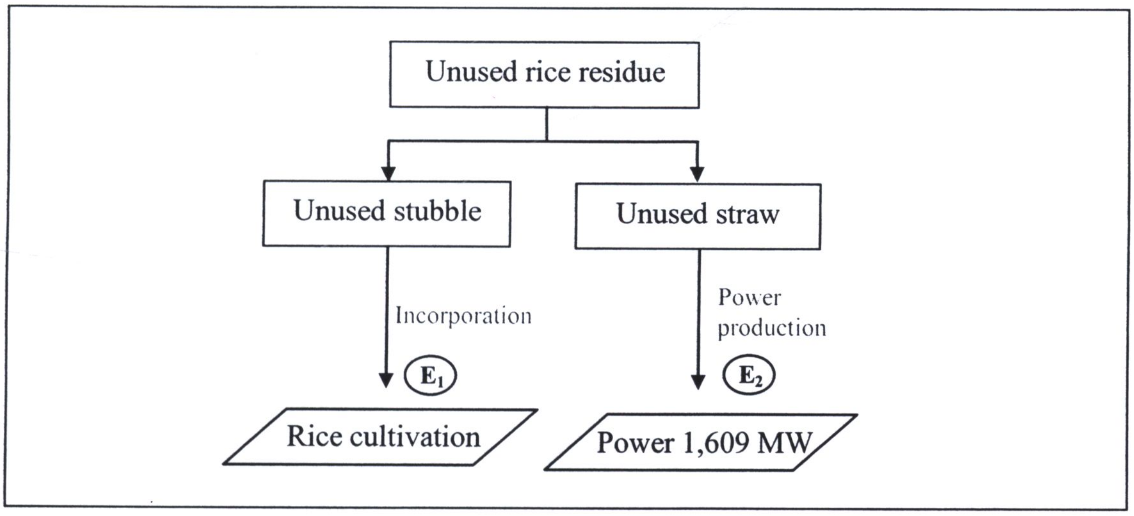

Figure 7.3 Structure of Scenario 2

Scenario 3: Zero open burning by energy and agricultural purpose

This scenario is based on demand of utilization for agricultural and energy purpose. Availability of residue is a main factor for residue utilization system [Summers, M.D. et al., 2003; Gadde, B., 2009].

In case of demand for agricultural purpose, too much of soil incorporating residue may the cause of increasing of weeds and diseases [Summers, M.D. et al., 2003] and tends to clog field implement [Kadam, K. et al., 2000]. This study assumes the optimum of soil incorporating residue should equal to the amount of carbon from organic matter that currently used for rice cultivation. About 3.125 tons/ha of organic matter is used for rice cultivation [Department of Agriculture]. The carbon and nitrogen ratio (C/N) is about 0.13-0.26 and 0.119 for organic matter and rice residue respectively [Rice Thailand, 2010]. To get the rice residue-nutrients as organic matter-nutrient, it needs to use rice residue about

1.6 times of amount of organic matter. So, the optimum amount of rice residue is about 8.2 tons/ha. Based on the estimation of unused rice residue in unit area found the average amount of unused rice residue is only about 7.7 tons/ha. Therefore, the amount of unused rice residue is not enough for demand of incorporation. That means unused residue is inadequate even for basic rice plantation.

In case of demand for energy purpose; this study assumes the biomass power plant is able to use straw as a fuel for power production. Demand of fuel equals to installed capacity of biomass power plant that currently operates. The information of capacity of biomass power plant is shown in Chapter 6.3.1. The total demand of rice residue for energy production is about 7.6-12.6 Mt. The amount of unused straw is about 10.52-17.28 Mt. So, unused straw is enough for demand of energy purpose.

Based on demand of agricultural purpose and energy purpose, to get the highest benefit from utilization of unused rice residue, this study focuses on the demand for energy purpose first. For rice straw energy production, this study sets the transboundary of the resource that should be within the province. The power plant is located at the province that has power capacity higher than 10 MW and provincial capacity higher than 1. The provincial capacity estimates from the fraction between the amount of unused rice straw and the average distance in the province. The power and provincial capacity is shown in Appendix H. Table 7.2 and Figure 7.4 show the location that suitable for rice straw power production. According to the provincial and power capacity found only some of province qualifies for power production. Central region has the highest capacity for power production which included 9 provinces, 509 MW power capacities, followed by lower northern region (7 provinces, 386 MW), western region (5 provinces, 336 MW), eastern region (4 provinces, 127 MW), and upper northern region (4 provinces, 82 MW). The upper north-eastern, lower north-eastern, upper-southern, and lower-southern regions have low of capacity for power production due to the low of burned straw (straw for power production in this study means the unused straw that burned in the field). So, unused straw in 29 provinces is used for energy purpose and unused straw in 47 provinces is used for agricultural purpose.

Scenario 3's emission includes (1) emission from unused straw power production based on the power capacity higher than 10 MW and provincial capacity higher than 1 and (2) emissions from rice cultivation due to the left of unused straw from energy purpose is incorporated into the soil. See Figure 7.5 for structure of Scenario 3.

Table 7.1 Base line and 3 scenarios to validate the optimal utilization of unused rice residue

	Open burning	Incorporation	Heat and Power production
Base case	Unused rice residue (stubble and straw)	Unused rice residue (stubble and straw) left after burned	Coal
Scenario 1	-	Unused rice residue (stubble and straw)	Coal
Scenario 2	-	Unused rice stubble	Unused rice straw
Scenario 3	-	Unused rice stubble and unused rice straw in 47 provinces	Unused rice straw in 29 provinces (1,439 MW) and coal 170 MW

Table 7.2 Straw power plant location based on power and provincial capacity (descending)

Location	Provincial capacity (kton/km)	Power capacity (MW)
Suphanburi	33.05	186
Chainat	36.59	111
Ayuthaya	36.18	110
Nakornsawan	14.93	86
Pichit	20.90	83
Pitchsanulok	10.55	70
Lopburi	14.86	69
Kampangphet	10.95	64
Angthong	34.43	62
Chachoengsao	14.59	60
Singburi	32.69	55
Nakonprathom	20.46	55
Sukothai	8.36	41
Pathumthani	16.43	38
Ratchaburi	7.73	36
Saraburi	9.66	34
Chiangrai	5.21	34
Petchaburi	6.97	33
Prachienburi	6.69	31
Utaradit	4.59	26
Kanchanaburi	3.06	26
Uthaithani	4.31	21
Petchabun	3.13	20
Nakornnayok	6.68	18
Sakaew	3.86	18
Nonthaburi	12.77	17
Bangkok	5.75	13
Chiangmai	1.20	11
Payao	2.13	10

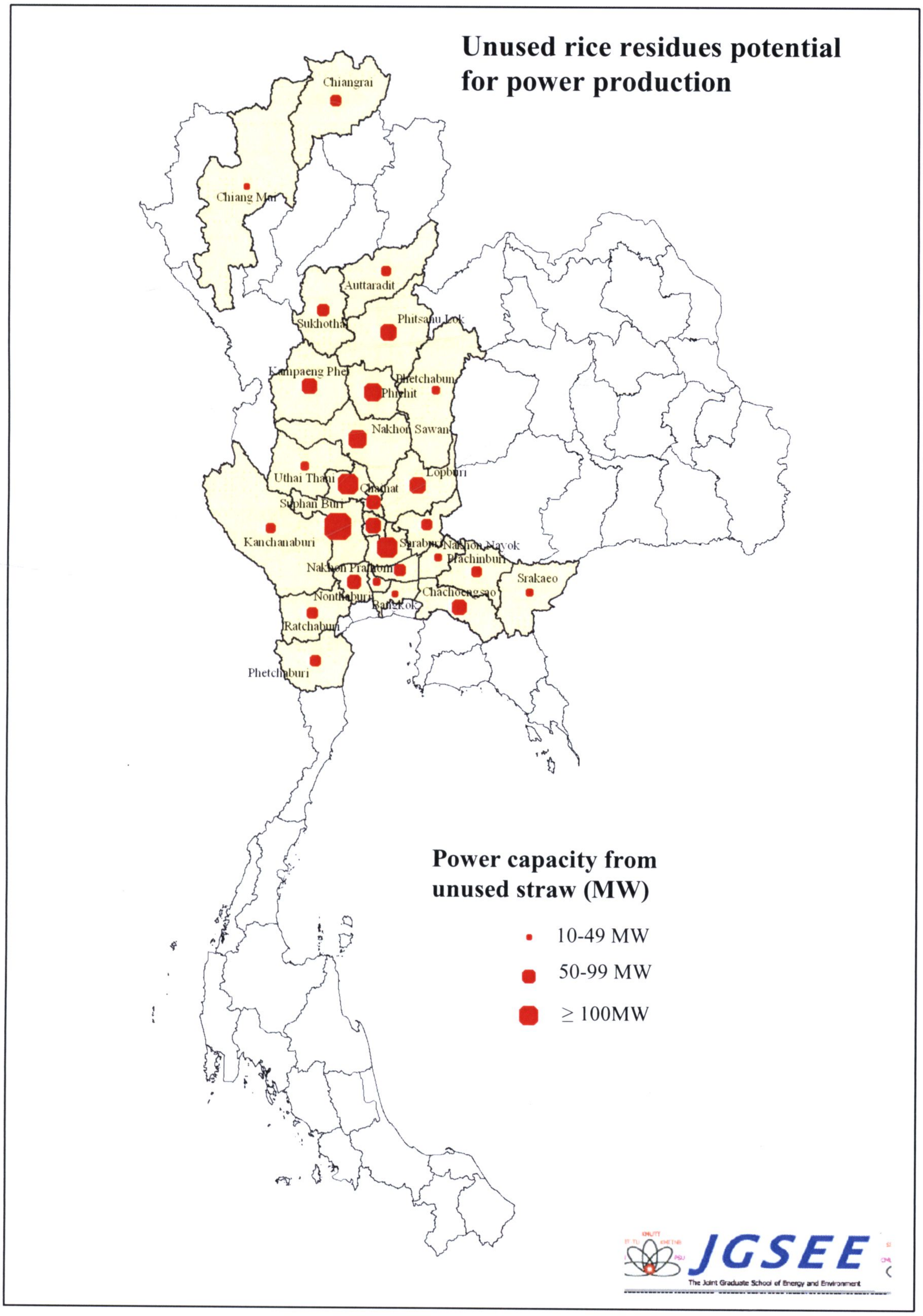

Figure 7.4 Spatial distribution of the straw power plant

(Based on power and provincial capacity)

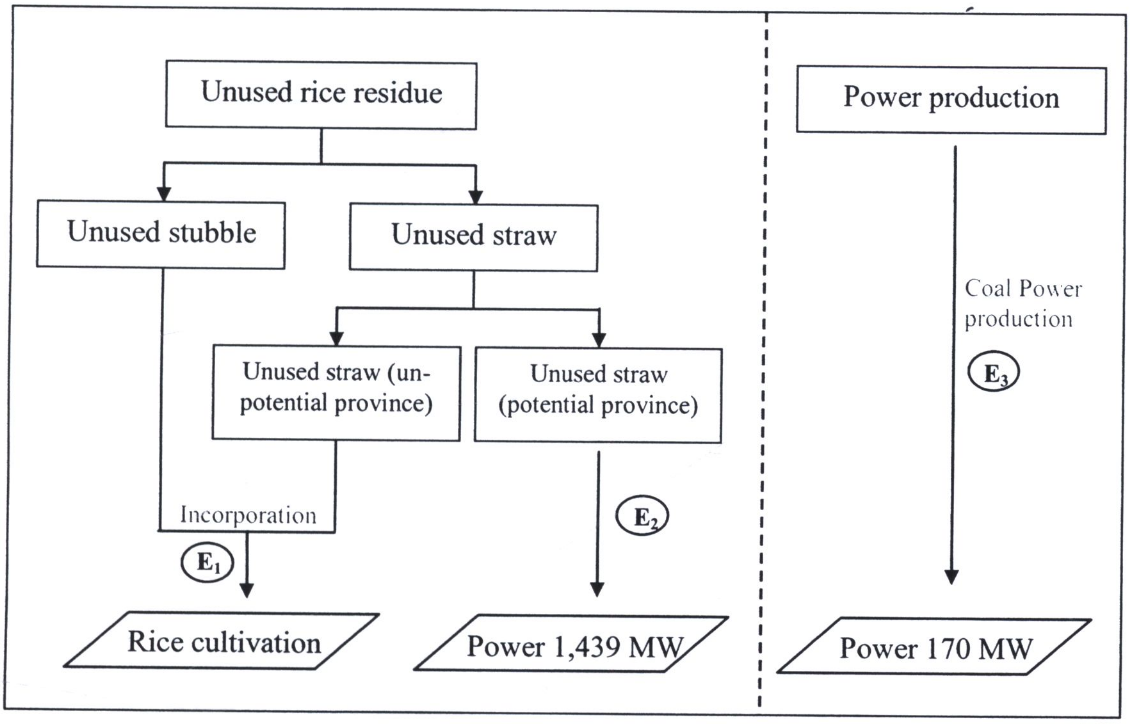

Figure 7.5 Structure of Scenario 3

7.3 Results and Discussion

7.3.1 GHG emissions reduction from utilization

Table 7.3 shows GHG emissions from utilization of unused residue for base line and each scenario. CO_2 emission from rice straw open burning and rice straw power production are not reported because there are considered as neutral GHG [IPCC, 2006].

Table 7.3 GHG emissions from utilization of unused rice residue classified by scenario

	Emission (Mt CO_{2eq})[a]			**Total GHG emission (Mt CO_{2eq})**
	Open burning	**Incorporation**	**Power production**	
Base case	0.89[b]	6.46	44.12	51.47
Scenario 1	0	15.03	44.12	59.15
Scenario 2	0	6.46	0.293[b]	6.75
Scenario 3	0	13.22	1.19	14.41

Remark a include CO_2, GWP of CH_4 = 21 and GWP of N_2O = 310
b exclude CO_2 neutral GHG

Base line emissions

Base line emissions include emissions from open burning of unused residue, emissions from rice cultivation in the burned area due to incorporate residue after burned into the soil, and emissions from 1,609 MW of power production by coal/lignite in thermal power plant. The base line GHG emissions are about 51.5 $MtCO_{2eq}$ which contributes from open burning 0.89 $MtCO_{2eq}$ (emission estimation is shown in Chapter 4), rice cultivation in burned area (emission estimation is shown in Chapter 5) 6.5 $MtCO_{2eq}$, and lignite power production 44.1 $MtCO_{2eq}$ (emission estimation is shown in Chapter 6). The information of emission from base line scenario by species is shown in Table 7.4. From these results, it can be seen that 14% of all GHG emission in the base case is non-CO_2 group and 86% of emission is CO_2.

Table 7.4 Information of base line emission by species

	GHG emissions (Tg)			
	CO_2	**CH_4**	**N_2O**	**CO_{2eq}**
E1 (from burning)	0.00	0.03	8.00E-04	0.89
E2 (from rice cultivation)	0.00	0.31	0.00	6.46
E3 (from coal power production)	44.11	6.00E-05	1.00E-06	44.12
Total	**44.11**	**3.40E-01**	**8.01E-04**	**51.47**

Scenario 1: Zero open burning by agricultural purpose

Emissions from Scenario 1 include (1) emissions from rice cultivation that unused residue is incorporated into the soil and (2) emissions from heat or power production by coal/lignite in thermal power plant. The overall emission in this scenario is about 59.15 $MtCO_{2eq}$ included CO_2 44.1 $MtCO_{2eq}$ and non-CO_2 15.04 $MtCO_{2eq}$. Rice cultivation in the burned area when incorporates all of unused residues into the soil contributes non-CO_2 15.03 $MtCO_{2eq}$ (emission estimation is shown in Chapter 5), coal/lignite power production contributes CO_2 44.1 $MtCO_{2eq}$ and non-CO_2 0.01 $MtCO_{2eq}$ (emission estimation is shown in Chapter 6). The information of emission from Scenario 1 by species is shown in Table 7.5.

Table 7.5 Information of Scenario 1's emission by species

	GHG emissions (Tg)			
	CO_2	CH_4	N_2O	CO_{2eq}
E1 (from rice cultivation)	0.00	0.72	-	15.03
E2 (from coal power production)	44.11	6.00E-05	1.00E-06	44.12
Total	**44.11**	**0.72**	**1.00E-06**	**59.15**

If substituting open burning by incorporation (Scenario 1), it has no profit from heat production. The net of GHG emission mitigation from base line is about 7.9 $MtCO_{2eq}$. 0.89 $MtCO_{2eq}$ of GHG emissions from open burning are avoided. 8.6 $MtCO_{2eq}$ from rice cultivation has increased due to the increasing of amount of residue incorporated into the soil (see Table 7.6 and Figure 7.6).

Table 7.6 Emission reduction of each scenario as compared to base line

	Emission reduction from base case ($Mt\ CO_{2eq}$)			Net emissions reduction ($Mt\ CO_{2eq}$)
	Open burning	**Incorporation**	**Power production**	
Scenario 1	-0.89	8.57	0.00	7.68
Scenario 2	-0.89	0.00	-43.827	-44.717
Scenario 3	-0.89	6.76	-42.93	-37.06

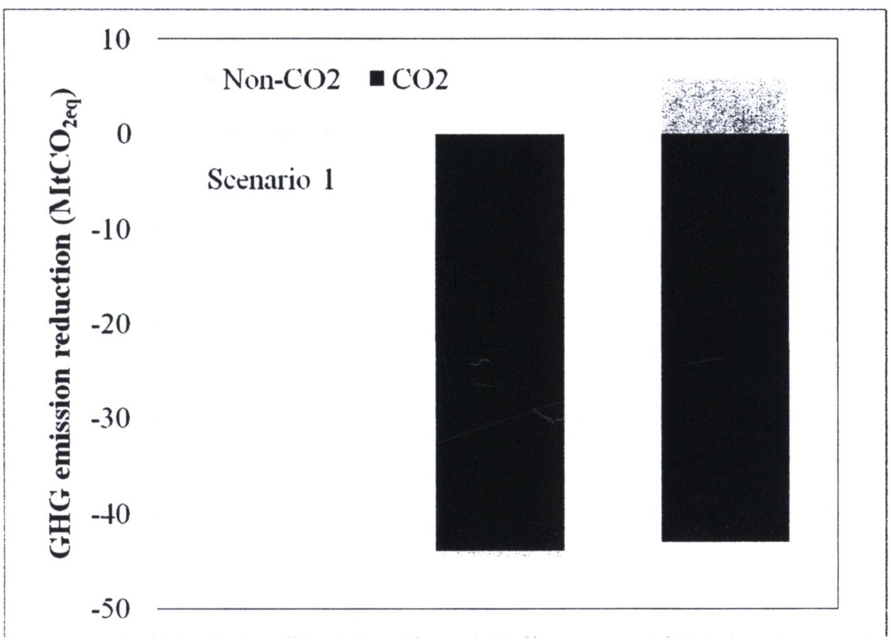

Figure 7.6 GHG emission reductions from each scenario

Scenario 2: Zero open burning by energy purpose

Emissions from Scenario 2 include (1) emissions from rice cultivation in the burned area due to incorporate unused stubble into the soil and (2) emissions from unused straw for heat or power production. The overall emissions in this scenario is about 6.8 $MtCO_{2eq}$ included CO_2 0.16 $MtCO_{2eq}$ and non-CO_2 6.59 $MtCO_{2eq}$. Rice cultivation in the burned area when incorporates unused stubble into the soil contributes non-CO_2 6.5 $MtCO_{2eq}$ (emission estimation is shown in Chapter 5), unused straw power production contributes CO_2 0.16 $MtCO_{2eq}$ and non-CO_2 0.14 Mt of CO_2 (emission estimation is shown in Chapter 6). The information of emission from Scenario 2 by species is shown in Table 7.7.

Table 7.7 Information of Scenario 2's emission by species

	GHG emissions (Tg)			
	CO_2	**CH_4**	**N_2O**	**CO_{2eq}**
E1 (from rice cultivation)	0.00	0.31	0.00	6.46
E2 (from straw power production)	0.16	1.60E-03	3.27E-04	0.29
Total	**0.16**	**0.31**	**1.00E-04**	**6.75**

If substituting open burning by power production (Scenario 2), it would provide capacity of 1,609 MW and about 44.7 $MtCO_{2eq}$ of GHG emissions are avoided. The avoid emission covers 0.89 $MtCO_{2eq}$ reduction from open burning, and 43.8 $MtCO_{2eq}$ emission reduction from power production (see Table 7.6 and Figure 7.6 for information).

Scenario 3: Zero open burning by energy and agricultural purpose

Based on thermal combustion at 20% of plant efficiency, 1 MWh requires 1.45 tons of straw and contributes 0.03 kg of CO_{2eq} (exclude neutral CO_2; the estimation of carbon intensity is shown in Chapter 6). The total unused straw availability for power production in the highest provincial capacity is about 12.97 Mt which about 1,439 MW of power capacity; will be emit CO_2 0.14 $MtCO_{2eq}$ (contributed from transportation and start-up engine) and non-CO_2 0.12 $MtCO_{2eq}$. To produce coal-power 170 MW, it contributes CO_2 0.93 $MtCO_{2eq}$ and non-CO_2 0.003 $MtCO_{2eq}$.

The overall amount of unused straw is about 10.1-16.5 Mt. The amount of unused straw that left from energy production and incorporated into soil is about 1.0 Mt or about 7%. A ton of incorporated straw causes of 0.015-0.130 $MtCH_4$ or about 0.32-2.74 $MtCO_{2eq}$ from rice cultivation (Chapter 5 shows the estimation of emission from rice cultivation due to straw is incorporated into the soil). 1.0 Mt of unused straw incorporated into the soil and all of unused stubble emits about 13.2 $MtCO_{2eq}$ from rice cultivation. The information of emission from Scenario 3 by species is shown in Table 7.8.

If substituting open burning by energy and agricultural purpose (Scenario 3), it would provide capacity of 1,439 MW and about 37.1 $MtCO_{2eq}$ of GHG emissions are net avoided. The avoid emissions cover 0.89 $MtCO_{2eq}$ reduction from open burning and 42.9 $MtCO_{2eq}$ emission reduction from power production. 6.8 $MtCO_{2eq}$ from rice cultivation has increased due to the increasing of amount of residue incorporated into the soil (see Table 7.6 and Figure 7.6 for information).

Table 7.8 Information of Scenario 3's emission by species

	GHG emissions (Tg)			
	CO_2	**CH_4**	**N_2O**	**CO_{2eq}**
E1 (from rice cultivation)	0.00	0.63	0.00	13.22
E2 (from straw-power production)	0.14	1.43E-03	2.92E-04	0.26
E3 (from coal-power production)	0.93	2.47E-05	9.28E-06	0.93
Total	1.07	0.63	3.02E-04	14.41

7.3.2 Optimal utilization of unused rice residue

Based on the result in Section 7.3.1 found the utilization of unused rice straw for agricultural purpose (Scenario 1) is the cause of increasing of GHG emissions which the net of 7.7 $MtCO_{2eq}$. The utilization of unused rice straw for energy purpose (Scenario 2) mitigates GHG emissions about 44.7 $MtCO_{2eq}$ and also obtains power about 1,609 MW (median of the range 1,221 to 1,998 MW). The utilization of unused rice straw for energy and agricultural purpose (Scenario 3) net mitigates GHG emissions about 37.1 $MtCO_{2eq}$, obtains power 1,439 MW.

Take into consideration on the reduction of CO_2 emissions found Scenarios 2 and 3 have the similar amount of CO_2 emission reduction which reduced by 43.95 $MtCO_{2eq}$ and 43.04 $MtCO_{2eq}$ respectively.

Take into account on the non-CO_2 GHG emissions found scenario 2 has the largest of emission reduction which reduced by 0.77 $MtCO_{2eq}$, whereas non-CO_2 GHG emission in Scenarios 2 and 3 have increased 7.7 $MtCO_{2eq}$ and 6.0 $MtCO_{2eq}$ respectively.

When considering the total CO_2 and non-CO_2 GHG emissions found Scenario 2 is the most suitable option in the of GHG emission reduction which net mitigated about 44.7 $MtCO_{2eq}$, followed by Scenario 3 which net mitigated 37.1 $MtCO_{2eq}$.

As these results demonstrate, the emission from rice residue open burning can be reduced by using rice residue for agricultural purpose or energy purpose. No matter using for agricultural purpose or energy purpose, it can avoid CO_2 emission from open burning. Take into consideration on utilization for energy purpose, the decreasing of CO_2 GHG emission has higher affected significantly than non-CO_2 GHG emission due to less of non-CO_2 GHG emission emitted from power production. Consideration on utilization for agricultural purpose, the amount of CO_2 is constant while non-CO_2 is increased because of incorporate rice residue is increasing the organic carbon into soil, enhancement CH_4 from rice cultivation. It demonstrates, the incorporation of rice residue can reduce emission from open burning but the net of emission is still negative environment. The rice straw power production is more suitable for open burning emission mitigation in term of environmental friendly. Furthermore, the unused straw also has a high potential in term of amount and qualification for power production.

In term of implementations, the financial feasibility should be considered. One of the main costs of biomass power plant is transportation cost especially for rice straw (when comparing on another type of biomass as wood, bagasse, and so on). The control of the quantity of residue and transportation distance is a main factor for biomass power plant implementation. From this background demonstrates only some of unused rice straw is suitable for energy purpose. In some area that unsuitable for energy purpose as too little of unused straw, too far from the power plant, and so on, the unused straw should be used for agricultural purpose. Therefore, the optimize solution for rice residue burning emission mitigation in terms of environment and implementation is used for agricultural and energy purposes. Which purpose should be used depends on the suitable area.

7.4 Conclusions

This part validated the optimized utilization of unused rice field residues constituted of fraction of residues burned in the field by comparing emissions from 3 developed scenarios with base line. The 3 scenarios were developed based on assumption base line and each scenario must be the same outcome (3.9 Mha of rice cultivation; 1,221-1,998 MW (1,609

MW) of power production). The optimized utilization of unused rice field residue was the option that had the highest of emission mitigation.

Base line was the actual activity which was the burning of unused rice residue, the incorporation after burning in pre-cultivation season, and lignite power production. 3 scenarios for mitigation emissions from burning of unused residue included (1) zero open burning by agricultural purposes (all of unused straw was incorporated into soil), (2) zero open burning by energy purposes (all of unused straw was used for power production), and (3) zero open burning by energy and agricultural purposes (power plant at the high of power and provincial capacity, the otherwise is incorporated into soil).

The total emissions in base line was about 51.5 $MtCO_{2eq}$ which included 0.9 $MtCO_{2eq}$ from rice residue open burning, 6.5 $MtCO_{2eq}$ from rice cultivation in the field that incorporation after burning rice residue, and 44.1 $MtCO_{2eq}$ from 1,221-1,998 MW lignite power production.

The total emissions in Scenario 1 which related on utilization in agricultural purpose was about 59.2 $MtCO_{2eq}$ included 44.1 $MtCO_{2eq}$ from 1,221-1,998 MW lignite power production and 15.0 $MtCO_{2eq}$ from rice cultivation in the field that incorporation unused straw into the soil. The net emissions were 7.7 $MtCO_{2eq}$ increased from the base line.

The total emissions in Scenario 2 related to utilization in energy purpose was about 6.8 $MtCO_{2eq}$ included 0.3 $MtCO_{2eq}$ (exclude neutral CO_2) from 1,221-1,998 MW unused straw power production and 6.5 $MtCO_{2eq}$ from rice cultivation in the field. The net of emission mitigation of Scenario 1 was about 44.7 $MtCO_{2eq}$.

The total emissions in Scenario 3 related to utilization in energy and agricultural purpose was about 14.4 $MtCO_{2eq}$ included 1.2 $MtCO_{2eq}$ from power production and 13.2 $MtCO_{2eq}$ from rice cultivation in the field that incorporation left of unused straw into the soil. The net emission mitigation of Scenario 3 was about 37.1 $MtCO_{2eq}$.

Regarding to emission reduction in each scenario found no matter the use for agricultural purpose or energy purpose, it can reduce CO_2 emissions from the open burning. Using for energy purpose can mitigate CO_2 and non-CO_2 emissions whereas using for agricultural purpose can mitigate only CO_2 emissions. So, stop open burning by energy purpose is the most beneficial option in term of environmental friendly. To use rice straw for energy purpose, the financial feasibility of the power plant should be considered.