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GREENHOUSE GAS MITIGATION ANALYSIS
LAND USE, LAND USE CHANGE AND FORESTRY, AND AGRICULTURE

Phnom Penh, June 2001

GREENHOUSE GAS MITIGATION ANALYSIS LAND USE CHANGE AND FORESTRY, AND AGRICULTURE

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ABBREVIATIONS

ALGAS	Asia Least Cost Greenhouse Gas Abatement Strategy
ARD	Associates in Rural Development
CCEAP	Climate Change Enabling Activity Project
CERI	Carbon Emissions Reduction Initiative
CH_4	Methane
CO	Carbon Monoxide
CO_2	Carbon Dioxide
COMAP	Comprehensive Mitigation Analysis Process Model
COP	Conference of the Parties
DFW	Department of Forestry and Wildlife
FAO	Food and Agriculture Organization
FP	Forest Protection
Gg	Gigagrame
GHG	Greenhouse Gas
GTZ	German Technical Cooperation
IPCC	Intergovernmental Panel on Climate Change
IRRI	International Rice Research Institute
JAFTA	Japan Forest Technical Association Monitoring Project
LUCF	Land Use Change and Forestry
MAFF	Ministry of Agriculture, Forestry and Fisheries
MAI	Mean Annual Increment
MoE	Ministry of Environment
N_2O	Nitrous Oxide
NPV	Net Present Value
O&M Cost	Operational and Maintenance Cost
ppmv	Part per Million by Volume
PPM	Part per Million
PV	Present Value
RFG	Reforestation without Rotation Using Fast Growing
RLG	Reforestation without Rotation Using Slow Growing
RLR	Reforestation with Long Rotation
RSR	Reforestation with Short Rotation
tC	Tonne Carbon
UNDP	United Nations Development Programme
UNFCCC	United Nations Framework Convention on Climate Change

PREFACE

Climate change is a global problem which has brought countries throughout the world to work together to mitigate the problem under an international convention called the United Nations Framework Convention on Climate Change (UNFCCC). The Kingdom of Cambodia ratified the Convention on 18^{th} December 1995 and the Convention entered into force on 17^{th} March 1996. Through an agreement between the Government of Cambodia and UNDP/Global Environment Facility (GEF), Cambodia has received funding from UNDP/GEF to implement a three-year project called *Enabling Cambodia to Prepare its First national Communication in response to the UNFCCC* (Climate Change Enabling Activity Project: CCEAP). This project started in January 1999 with an aim of assisting Cambodia in preparing its First National Communication in response to the UNFCCC.

The first National Communication under the UNFCCC is mandatory for countries that have ratified the convention. For Cambodia, the activities that need to be carried out in the preparation for this communication are:

- Establishment of a national greenhouse gas (GHG) inventory;
- Assessment of GHG mitigation options; and
- Assessment of the vulnerability of Cambodia to climate change and development of adaptation options to cope with the climate change.

The GHG mitigation analysis of forestry and agriculture sectors was carried out by the National Technical Committee (NTC), members of which are representatives from the Ministry of Environment; Ministry of Agriculture, Forestry and Fisheries; Ministry of Public Works and Transportation; Ministry of Water Resources and Meteorology; Ministry of Industry, Mines and Energy; and Royal University of Phnom Penh. This report discusses some of the potential GHG mitigation options in two non-energy priority sectors, forestry and agriculture, in Cambodia.

The National Technical Committee has received support from many organizations and individuals, both from within and outside Cambodia during the preparation of this report. We would like to take this opportunity to sincerely express our thanks to all of them. Support provided by the consultants from Indonesia (Dr. Rizaldi Boer) and the Philippines (Ms. Mila Jude) is greatly appreciated. Their technical assistance has been very valuable to building capacity and motivating the national team. We would like to thank the staff of the National Communication Support Programme and UNITAR for their advice and support in organizing a training workshop on GHG mitigation. We also thank the UNDP Office in Phnom Penh for its valuable support to the project.

Finally, we realize that many things still need to be done in the future. We are always open to any constructive inputs, which, we believe, could improve our future studies.

August 2001

Dr. Mok Mareth
Minister for the Environment

EXECUTIVE SUMMARY

Introduction

Climate change is one of the most complex and challenging environmental problems the world is facing. The complexities include the wide range of greenhouse gas (GHG) emissions by source and removal by sinks. Carbon dioxide is one of the GHGs in the atmosphere that absorbs long wave radiation which regulates the earth's temperature. Without the presence of GHGs in the atmosphere, air temperature during night time might drop down to 184^{o}C below zero. Thus these GHGs are very important for earth's life. During the period 1850 to 1998, approximately 270 (±30) Gt of carbon was released into the atmosphere as carbon dioxide (CO_2) as a result of fossil fuel burning and cement production (67%), and land use and land use change (33%), predominantly from forested areas. About 40% of these emissions remain in the atmosphere while the other 60% was absorbed by the ocean and terrestrial ecosystems. Carbon dioxide that is dissolved into the oceans is transferred progressively to the deep ocean, and the carbon content in this reservoir is continuously increasing. Thus, during the period 1850 to 1998, the atmospheric CO_2 concentration increased by about 28%, i.e. from 285 ppmv at the end of 19th century to 366 ppmv at the end of 20th century. This increased CO_2 concentration is believed to be causing an increase in global temperature.

Under the United Nations Framework Convention on Climate Change (UNFCCC), developed countries (Annex-I countries) agreed to reduce GHG emission at the sources and increase GHG uptake by sinks, while developing countries could participate in reducing their emission or increasing the uptake on a voluntary basis using national, multilateral or bilateral funds. This study evaluated some mitigation options for the agriculture and forestry sectors.

Forestry Sector

In the forestry sector, GHG mitigation options can be classified into three broad categories:

1. Conservation of forest carbon by controlling deforestation, protecting forests, changing harvesting regimes, and controlling other anthropogenic disturbances, such as fires and pest outbreaks;

2. Enhancing and expanding carbon sinks by increasing forest area and/or biomass and soil carbon density and by increasing storage in durable wood products; and

3. Substituting the use of fossil fuel-based energy generation with biomass-based energy or the use of biomass products in place of energy-intensive materials (i.e. metals, plastic, glass, etc.) which require large amounts of energy for extraction and processing.

This study evaluates forest protection (FP) which falls under category one, and reforestation with short (RSR) and long rotation (RLR), and reforestation without rotation using fast (RFG) and slow growing species (RLG) which fall under category two. Results of the analysis are presented in Table 1.

Table 1: Mitigation Potential and Cost Effectiveness of the Five Mitigation Options

Mitigation Option	Mitigation Potential (t C/ha)	Initial Cost		PV of Cost		NPV of Benefit	
		$/tC	$/ha	$/tC	$/ha	$/tC	$/ha
RLR	120	0.29	35.4	0.41	48.8	0.05	6.0
RSR	43	1.10	47.2	1.78	76.2	4.66	199.8
RLG	141	0.18	25.4	0.28	39.2	-0.26	-36.4
RFG	92	0.28	25.4	0.43	39.2	-0.32	-29.1
FP	137	0.02	2.5	0.51	70.0	-0.77	-105.7

Table 1 shows that among the options, RLG has the highest mitigation potential (141 tC/ha) while RSR has the lowest (43 tC/ha). The cost required to remove one tonne of carbon from the atmosphere per one life cycle was between 0.28 and 1.78 US$, while the benefit ranged between –0.77 and 4.66 US$/tC. Using the above information, three mitigation scenarios were developed, namely the baseline scenario, potential scenario and mitigation scenario.

The baseline scenario is a scenario to evaluate mitigation potential of LUCF sector in the future if the rate of tree planting (sink enhancement) on degraded land is assumed to be the same as the historical planting rate and no efforts are made to protect the protection forest from being deforested.

The mitigation scenario is a scenario to evaluate mitigation potential of LUCF sector in the future if the rate of tree planting and efforts to protect the forest from deforestation follow government plans.

The potential scenario is a scenario to evaluate mitigation potential of LUCF sector in the future if all degraded lands and forests are reforested and efforts to protect the forest from deforestation are maximum.

Under the baseline scenario, the total degraded land that needed to be used for implementing the options (RSR, RLR, RFG, and RLG) was approximately 16,320 ha. The total carbon that would be abated from the atmosphere was approximately 1.2 million tonnes and the total investment was approximately 0.62 million US$. The highest benefit was given by RSR. In total, by implementing all options, the total net benefit would reach approximately 1.5 million US$ (Table 2)[1]. Under the mitigation scenario, the total carbon that would be abated, investment cost, life cycle cost and benefit would increase by approximately 120 times from the baseline, while under the potential scenario the benefit would increase by approximately 390 times the baseline scenario.

[1] The benefits of reduced GHG emissions have been converted to US$ values using the following formula:
NPV = Initial Cost + PV (future cash flow) and $PV = C/(1+r)^t$

Table 2: Mitigation Potential, Investment Cost, Present Value of Cost and Net Present Value of Benefit of the 3 Scenarios

Mitigation Option	Mitigation Potential (t C/ha)	Land Available (ha)	Carbon Mitigation (t C)	Investment Cost (US$)	PV of Cost (US$)	NPV of Benefit (US$)
Scenario 1: Baseline						
RLR	120	3,084	369,954	109,088	150,545	18,674
RSR	43	8,340	357,526	393,256	635,808	1,666,456
RLG	141	1,322	186,060	33,506	51,888	-48,063
RFG	92	3,574	328,815	90,589	140,291	-103,962
Total		**16,320**	**1,242,356**	**626,439**	**978,532**	**1,533,104**
Scenario 2: Mitigation						
RLR	120	374,900	44,965,788	13,259,030	18,297,835	2,269,700
RSR	43	1,013,620	43,455,139	47,797,983	77,278,771	202,547,952
RLG	141	160,672	22,614,528	4,072,416	6,306,719	-5,841,834
RFG	92	434,408	39,965,573	11,010,607	17,051,500	-12,635,993
FP	137	33,791	4,626,933	84,478	2,366,742	-3,570,247
Total		**2,017,391**	**155,627,961**	**76,224,514**	**121,301,567**	**182,769,578**
Scenario 3: Potential						
RLR	120	1,134,000	136,012,669	40,105,958	55,347,353	6,865,396
RSR	43	3,066,000	131,443,253	144,579,501	233,753,089	612,667,730
RLG	141	486,000	68,404,500	12,318,258	19,076,585	-17,670,398
RFG	92	1,314,000	120,888,000	33,304,921	51,577,434	-38,221,395
FP	137	70,182	9,609,823	175,455	4,915,561	-7,415,157
Total		**6,070,182**	**466,358,244**	**230,484,093**	**364,670,022**	**556,226,175**

Agriculture Sector

Options to reduce GHG emission from the agriculture sector are also abundant. GHG emissions reduction, in particular methane (CH_4), from livestock can be done by reducing the emissions from enteric fermentation and manure management. Some of the available options are:

1. CH_4 mitigation from enteric fermentation: providing mineral blocks/MNB, molasses-urea block, urea treatment of straw, chemical/mechanical feed treatment, genetic improvements and others; and

2. Improved management of manure storage to reduce CH_4 emissions and/or production of biogas from manure .

Methane emission reduction from rice paddy can be done by controlling irrigation water (intermittent drainage, 3-4times per season), low CH_4 emitting varieties, using composted organic matter, direct seeded nurseries, zero tillage, and ammonium sulfate usage.

Evaluation of mitigation options in the agricultural sector in this study was limited to intermittent irrigation applied to dry season rice (DSInt), direct seeded applied in both dry and wet seasons (DSDirect and WS Direct), organic matter management applied for both seasons (DSManure and WSManure), and zero tillage applied in both seasons (DSZero and WSZero). The results of the analysis showed that mitigation of the options ranged from 71 to 304 kg CH_4 per ha per season (Table 3). Using mitigation potential provided by studies conducted in Indonesia (Pawitan et al., 1999), it was found that all options evaluated in this study gave positive benefit with a range of 10 to 71 US$/ha. In terms of methane reduction, the incremental benefit ranges between 116 to 774 US$/t CH_4 (Table 3). Based on profitability, yield, mitigation potential, applicability and acceptability of the options, it was found that options with low barrier are DSInt, DSManure, and WSManure, options with medium barrier are DSDirect, WS Direct and WSZero, while that with high barrier is DSZero.

Table 3: Mitigation Potential and Mitigation Cost of the Seven Options

No.	Options	Mitigation Potential (kg CH_4/ha/season)	Incremental Benefit	
			US$/ha	US$/t CH_4
1	Dry Season Intermittent	304	71	233
2	Dry Season Directed Seed	121	69	574
3	Dry Season Manure	71	46	651
4	Dry Season Zero	86	10	116
5	Wet Season Direct	108	55	514
6	Wet Season Manure	66	51	774
7	Wet Season Zero	74	45	607

To reduce methane emissions from the agriculture sector by approximately 10% of the 1994 total emissions (approximately 40 thousand tonnes of CH_4), the area that should be allocated for implementing the seven options is approximately 424,000 hectares. By implementing these options it is expected that rice production would increase by approximately 275,865 tonnes. If all rice growing areas used for implementing the seven options are considered, the production is expected to increase by approximately 1,460,736 tonnes. However, these efforts may require big investment.

INTRODUCTION

Climate change is one of the most complex and challenging environmental problems the world is facing. The complexities include the wide range of greenhouse gas (GHG) emissions by source and removal by sinks. Carbon dioxide is one of the GHGs in the atmosphere that absorbs long wave radiation which regulates the earth's temperature. Without the presence of GHGs in the atmosphere, air temperature during night time might drop down to 184 ^{o}C below zero. Thus these GHGs are very important for earth's life. During the period 1850 to 1998, approximately 270 (±30) Gt of carbon was released into the atmosphere as carbon dioxide (CO_2) as a result of fossil fuel burning and cement production (67%), and land use and land use change (33%), predominantly from forested areas. As a result, the atmospheric CO_2 concentration has risen from 285 ± 5 ppmv to 366 ppmv (i.e., approximately a 28 percent increase). About 40% of these emissions remain in the atmosphere while the other 60% was absorbed by the ocean and terrestrial ecosystems. Carbon dioxide that is dissolved into the oceans is transferred progressively to the deep ocean, and the carbon content in this reservoir is continuously increasing. Thus, during the period 1850 to 1998, the atmospheric CO_2 concentration increased by about 28%, i.e. from 285 ppmv at the end of 19th century to 366 ppmv at the end of 20th century. This increased CO_2 concentration is believed to be causing an increase in global temperature.

Reducing greenhouse gas is not an easy task, since in both developed and developing countries the sources and sinks of these emissions are directly tied to economic sectors, particularly the energy, industry, agriculture, forestry and waste management sectors. Although most developing countries recognize the seriousness of the issues, the limitation or reduction of greenhouse gas emissions is generally not a policy priority. In many cases, however, developing countries have started implementing measures which, while designed for social and economic policy goals, will contribute to the aim of limiting greenhouse gas emissions.

The United Nations Framework Convention on Climate Change (UNFCCC) entered into force in March 1996, less than two years after it had been signed by more than 150 counties. The convention establishes a set of commitments that should contribute to the overall objective of the UNFCCC which is the "stabilization of GHGs concentration in the atmosphere at a level that could prevent dangerous anthropogenic interference with the climate system. In the Kyoto Protocol, Parties in Annex I of the UNFCCC agreed to reduce their overall emissions of six GHGs by an average of 5 % below 1990 levels between 2008 and 2012. The Protocol also establishes an initial framework for emissions trading, joint implementation between developed countries, and a "Clean Development Mechanism" to encourage emissions reduction project between developed countries and developing countries. National mitigation assessment should consider implementing policies and technological options which lead to reduced GHG emissions and increased sinks in the future. The aim is to identify cost-effective mitigation options that can be implemented in the national context.

Cambodia ratified the UNFCCC in 18 December 1995. The Convention entered into force for Cambodia on March 17, 1996. As a developing country (non-Annex I) Party to the UNFCCC, Cambodia has accepted the commitment to produce a national communication to the COP within three years of the entry into force of the Convention for Cambodia, or the availability of financial resources in accordance with article 4, paragraph 3 of the Convention.

Other than its ratification of the UNFCCC, Cambodia has not yet established a policy framework targeted specifically at climate change concerns. While climate change has not been a specific focus for the government, many government activities and measures also contribute to the global effort to limit GHG emissions and develop GHG sinks. This includes creation and management of 23 protected areas covering approximately 20% of the country's land area; establishment of various legal instruments related to forest management, waste management and air pollution; and current efforts to eliminate uncontrolled logging.

In August 1998, the project document of Cambodia's Climate Change Enabling Activity Project (CCEAP) was signed by the Government of Cambodia and UNDP. The 3-year project started in January 1999 with the objective of preparing the first national communication in response to the UNFCCC. This is seen as the first step taken by the government in the actual implementation of the UNFCCC in Cambodia. It will allow the development of Cambodian expertise in each sector involved in the preparation of the national communication, enhance the institutional capacity in these fields, and increase the awareness of people and institutions concerning the UNFCCC and the global warming issues. The project also contributes to the global effort to increase the understanding of the sources and sinks of greenhouse gases, potential impacts of climate change, and effective response measures to achieve the ultimate objective of the UNFCCC which is "to stabilize greenhouse gas concentrations in the atmosphere at a level that would prevent dangerous anthropogenic interference with the climate systems".

The objectives of this study are:

- To evaluate the GHG mitigation options for the agriculture and forestry sectors in Cambodia;

- To assess the economic effectiveness of the options; and

- To evaluate the GHG mitigation options under baseline and mitigation scenarios.

Greenhouse Gas Mitigation Analysis

Section 1

LAND USE, LAND USE CHANGE AND FORESTRY (LULUCF)

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1.1. Introduction

Forests constitute both a sink and a source of atmospheric CO_2. Forests absorb carbon through photosynthesis, but emit carbon through respiration, decomposition and when trees are burned due to anthropogenic and natural causes. Managing forests in order to retain and increase their stored carbon will help reduce the rate of increase of atmospheric CO_2 and stabilize atmospheric concentration. Even though some degraded lands are unsuitable for forestry, there is considerable potential for mitigation through improved management of forestlands for carbon conservation, storage and substitution, while balancing other objectives.

There are many available GHG mitigation options in the land use and forest sector, which include reducing the rate of deforestation through switching to sustainable energy (e.g. biogas, solar, and sustainable produced firewood), increasing the efficiency of wood fuel use, measures to increase agricultural productivity; reforestation; and forest protection and conservation.

The objectives of the study are to: (1) evaluate the appropriate GHG mitigation options for the forestry sector in Cambodia and, (2) evaluate the impact of the implementation of the baseline scenario and mitigation scenario on forestry GHG emissions.

1.2. GHG Emissions from Land Use Change and Forestry

Currently, Cambodia's GHG emissions levels are low. According to the World Resources Report 1996-97 (WRR), land-use change in 1991 accounted for 35 million tonnes of CO_2 emissions, although these and any other estimates have to be acknowledged as extremely uncertain. The WRR estimated that energy and industrial-related emissions accounted for only 462,000 metric tonnes in the same year, and that methane emissions in 1989 were 1.1 million metric tonnes per year from a combination of rice and livestock production. Recovery of the country from its recent history, as well as economic development, is likely to dramatically increase land-use and energy related emissions of GHGs over time.

The inventory of GHG emissions by sources and removal by sinks indicates that in 1994, Cambodia removed 64,580 Gg and emitted 59,708 Gg of CO_2-equivalent. Therefore, in 1994, Cambodia was a net carbon sink country with a net total carbon removal of 5,142 Gg of CO_2 equivalent (MoE, 2001). The main source of carbon dioxide emissions was land use change and forest sector (LUCF; 97%), followed by energy (3%), while the contribution from the industry sector to total CO_2 emissions was insignificant. However, the capacity of the LUCF sector to uptake CO_2 was 43% higher than emissions, thus in total this sector could offset all other GHGs emissions from all other sectors. The CO_2 emissions from LUCF, energy and industry were approximately 45,214; 1,272 and 50 Gg respectively, while CO_2 removal by LUCF was 64,850 Gg.

It is important to note that if some of the assumptions used in the Land Use, Land Use Change and Forestry (LULUCF) sector in particular were changed, the country's GHG emission status may change considerably. Many studies indicated that biomass removals through illegal logging are quite significant. The World Bank report on illegal logging indicated that in 1997/98 at least 4.25 million m^3 of roundwood were removed from forests through illegal logging (World Bank, 1999). Thus, the effect of including illegal logging in the calculation of GHG emissions from LUCF may change the status of Cambodia significantly. For example, if illegal logging was included and the mean annual increment (MAI) or growth rate of evergreen, mixed & coniferous and deciduous forest was changed from the current values, emissions from LULUCF would change considerably and may change the country's status from a net sink to a net emitter. The detailed analysis, however, could not been done under this inventory due to the lack of reliable data on illegal logging and local MAI. At present the MAI used for the analysis was not local data but IPCC default values for evergreen and Thailand data for mixed & coniferous and deciduous forests. This indicates how important this sector is in regards to GHG emissions. Therefore identification of GHG mitigation options in this sector is very important not only for reducing the emissions but also for the prosperity of the country.

1.3. Land Use, Land Use Change and Forestry in Cambodia

Cambodia as an agricultural economy, considers land use change and forestry as important issues related to climate change. Forests are among Cambodia’s most important natural resources. In ecological and environmental terms, Cambodia's forests are invaluable. Forests protect the soil from erosion, stabilize the watersheds and regulate water flow and local and regional climate systems. Forests have long offered rural Cambodians essential livelihood benefits, supplementing agricultural or fishing activities by providing construction materials, medicines, food, and market goods. Wood fuel accounts for over 80% of the total energy requirement of the country and much of the wood fuel is a by-product of forest reduction.

1.3.1. Status and Trends in Forest Sector

The land use analysis by the Ministry of Agriculture, Forestry and Fisheries (MAFF) showed that between 1973 and 1993 there were significant decreases in dry-land forest (down 1.1 million ha) and edaphic forest (down 316,900 ha). The annual rate of deforestation during the period was approximately 0.6% or equivalent to approximately 72,000 ha/year. In the period of 1973 to 1998, the annual rate of deforestation tended to increase from 0.6 to 0.9% (equivalent to approximately 101,000ha/year, Table 1.1). This figure reflects mainly a conversion of forest to agricultural land use. A significant proportion of the forest area was simply so severely degraded that it was re-classified as shrubland rather than forest.

Table 1.1 indicated that in the period between 1984-1998, approximately 1,323,000 ha of forest area changed into shrublands. An assessment of land cover in 1995 by the Japan Forest Technical Association Monitoring Project (JAFTA) and more recent work by the Mekong River Commission/GTZ Forest Cover Monitoring Project reveal a continuation of these trends. Between 1993-1997, approximately 345,000 ha of forest area were converted to agricultural land. The most recent data indicated that the total area of shrub land already reached 2,260,600 ha (World Bank/FAO/UNDP, Cambodia Forest Policy Assessment, April 1996). It was estimated that, if nothing was done to reduce the rate of deforestation, Cambodia’s forests would be completely destroyed within the next five years.

Table 1.1: Forest Area by Type (1973-1998)

	1973[1]	1984[2]	1993[1]	1994[3]	1998[2]	% Change per Year
A. Dry Land Forest	**11,678,600**	**11,277,000**	**10,568,600**	**10,307,000**	**10,086,000**	-0,61
Evergreen	6,876,400	4,126,000	4,763,300	4,027,000	4,094,000	
Mixed & Coniferous	9,300	1,130,000	987,100	1,527,000	1,395,000	
Deciduous	4,792,900	4,745,000	4,301,200	4,333,000	4,052,000	
Secondary/Regrowth		1,276,000	517,000	420,000	545,000	
B. Edaphic Forest	**1,032,500**	**660,000**	**715,600**	**422,000**	**428,000**	-3,46
Mangrove	94,600	95,000	85,100	76,000	77,000	
Flooded	937,900	565,000	370,700	346,000	351,000	
Flooded secondary			259,800			
Total Forest (A+B)	**12,711,100**	**11,937,000**	**11,284,200**	**10,729,000**	**10,514,000**	**-0,77**
C. Others	1,056,900	704,000	2,260,600	2,309,000	2,108,000	3,61
Forest plantation		4,000		75,000	85,000	
Agro-Forestry				66,000		
Shrubland	1,056,900	700,000	2,260,600	2,168,000	2,023,000	
Total (A+B+C)	**13,768,000**	**12,641,000**	**13,544,800**	**13,038,000**	**12,622,000**	

Source: [1] World Bank/FAO/UNDP (1996);
[2] MAFF and World Bank (1999) ;
[3] Estimated from annual change in World Bank/FAO/UNDP (1996).

1.3.2. The Root Causes of Deforestation

Deforestation, including reductions in tree density and cover, has been widespread in Cambodia. Deforestation is often associated with rural poverty and population growth, which force rural people to encroach onto forest areas to find new cultivatable land and to harvest forest products to increase their income. In 1998, Associates in Rural Development (ARD) stated that with the then current population growth rate of 3%, the population of Cambodia would double in size within the next twenty-five years, resulting in greater pressure on forest land.

Wood is the main source of cooking fuel in Cambodia. In 1996, it was estimated that half of all fuelwood was extracted from forests (Table 1.2). The production of fuelwood and charcoal in forest supply areas close to roads and rivers, may be greater than log production. Over the last thirty years the inability of the state to manage the forest resources has been largely due to the war which ended in 1998. In the last five years, logging increased due to the need for increased income. Log production reached the highest levels in Cambodia in 1997 with 4.3 million cubic meters being cut from over 7 million hectares of forests (Fig. 1.1). Illegal timber felling accounted for at least 92% of total production (Bottomley, 2000; see Appendix 1.1).

FAO (1994) and Global Witness (1996) reports, in addition to Government statistics, stated that there were 11 forest concessions covering 2.2 million hectares of forest before 1994. By 1999, there were 20 companies holding valid agreements for 24 concession blocks which covered an area of approximately 4,627,653 ha (see Appendix 1.2). Other studies indicate that approximately 6,464,021 hectares have been allocated for concessions (World Bank/FAO/UNDP, 1996). However, it was estimated that only 5.6 million hectares have substantial commercial value. The above facts suggest that logging activities, rural poverty and clearance of forests for agricultural purposes are major causes of deforestation in Cambodia.

Table 1.2: Fuelwood Extraction from 1961 to Present

Year	Total Fuelwood (million m^3)	Extraction from Forest (50%), (million m^3)
1961-1970	18	9
1971-1980	10	5
1981-1990	24	12
1990-present	6	3

Source: World Bank/FAO/UNDP (1996).

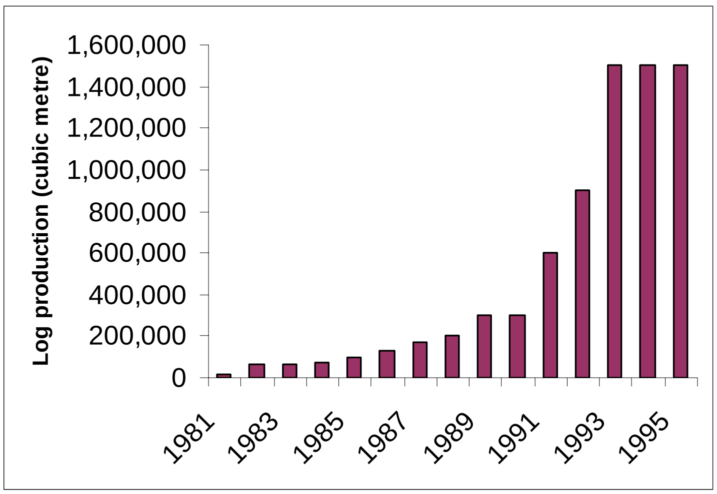


Figure 1.1: The Increase in Log Production from 1981-1995 (World Bank/FAO/UNDP, 1996)

From 1999 to 2000, the Royal Government of Cambodia reviewed the contractual compliance of the concessionaires. As a result of the review 11 forest concession agreements covering 16 concession areas (approximately 2,437,970 ha) were terminated. These forest areas have been declared as conservation forests. In addition, the Cambodian Government has also announced a crackdown on illegal logging and has closed down many sawmills. It is expected that these actions will lead to reduced illegal logging activities.

1.3.3. Protected Areas

The Royal Government of Cambodia fully recognizes the need for protecting forests for both economic values and environmental benefits. With the support of various donors, it has taken some decisive measures to protect the remaining forest. Cambodia also has a high percentage of the country designated as protected areas. As of 1993, all edaphic forests and some 2.8 million hectares of dry land forest were put under the National Protected Area System, which presently has 23 protected areas. The total protected area is 3,568,100 hectares, 19.7 % of the country's total land area. These areas are classified as National Parks, Wildlife Sanctuaries, Protected Landscapes and Multiple-Use Areas. Unfortunately, the effectiveness of management and protection of these areas is very limited. The effectiveness and long-term effect of the current forest and protected areas management practices remain questionable.

1.3.4. Community Forestry

Community forestry is an important forest management alternative to industrial forest concessions, in which the forest management authority is conveyed to local communities. Approximately 22 small scale community forests (WWF, 2000. Community Forestry Study Preparatory Report) have already been established in order to ensure the long term security and stability of the livelihood of rural communities that depend on forest products and to increase forest cover. Community forestry has been recognized as an effective strategy for sustainable forest management. To date, most of the community forest projects have focused on developing pilot projects to promote community based management to local communities and to train staff. Both MoE and MAFF have units dedicated to the development of community forestry.

1.3.5. Reforestation

From 1985 to 2000 the total area of forest plantation established was 8701 ha (see Table 1.1) which included trees planted on National Arbor Day. The rate of reforestation varies from year to year, beginning with 289 ha in 1985 and increasing to 897 ha in 2000 (Figure 1.2). Acacia and Eucalyptus are the most common tree species planted. The DFW also distributed 2 million seedlings of mixed tree species to local people and various institutions, and cooperated with NGOs conducting extension to local people to protect forests and actively plant trees, especially through school children. The DFW has been promoting the establishment of nurseries throughout Cambodia, selection of appropriate tree species for planting, and expansion of reforestation schemes, forest extension, and community forestry programs. According to a temporary assessment, there are 6 million hectares of degraded forest land that need to be rehabilitated from 2001 to 2005 (Department of Forestry and Wildlife, the Second Five-Year Plan for Forestry Sector, 2001-2002). The specific sites and detailed information is now being studied. As specified in the " Second Five-Year Plan for Forestry Sector, 2001-2005 ", tree planting programs will be implemented in many forms in provinces and towns with the objective of:

- Planting 50,000 ha/year of forest plantations;
- Planting 120ha/year on National Arbor Day; and
- Planting approximately 16,000ha/yr through people participation and community forestry.

The common tree species planted in Cambodia are *Acacia, Deperocarpus, Tectona grandis, Pahudia coohinchinnensis*, etc. In this study, planted trees are classified as reforestation with and without rotation. Acacia falls under category of reforestation with short rotation, and reforestation without rotation with fast growing species. From the 2000 Financial Proposal submitted to the government by the Department of Forestry and Wildlife, it was indicated that Acacia accounted for 73% of all trees planted in reforestation programs. *Tectona grandis*, mixed tree and *Pahudia coohinchinnensis* accounted for 8, 8 and 3%, respectively.

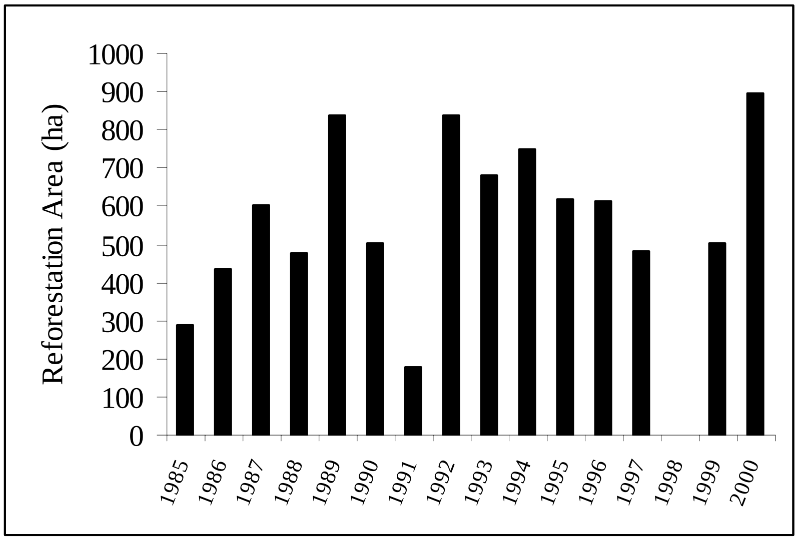


Figure 1.2: Reforestation Rate in the Period of 1985-2000 (DFW, Statistics of Reforestation)

1.4. Assessment of GHG Mitigation Options

Sathaye and Ravindranath (1997) noted that the mitigation options in forestry can be classified into three broad categories:

1. Conservation of forest carbon by controlling deforestation, protecting forests, changing harvesting regimes, and controlling other anthropogenic disturbances, such as fires and pest outbreaks;

2. Enhancing and expanding carbon sink by increasing forest area and/or biomass and soil carbon density and by increasing storage in durable wood products; and

3. Substituting the use of fossil fuel-based energy generation with biomass-based energy or the use of biomass products in place of energy-intensive materials (i.e. metals, plastic, glass, etc.) which require large amounts of energy for extraction and processing.

In this study, mitigation options evaluated were forest protection (FP) which falls under category one, and reforestation with short (RSR) and long rotation (RLR), and reforestation without rotation using fast (RFG) and slow growing species (RLG) which fall under category two. The option of fossil fuel substitution was not evaluated in this study due to a lack of data.

1.4.1. Methodology for Mitigation Assessment

The assessment of mitigation option was carried out using COMAP (Comprehensive Mitigation Analysis Process model). COMAP was developed by the Lawrence Berkeley National Laboratory (LBNL), USA to guide an analyst undertaking a comprehensive assessment of GHG mitigation efforts for land use change and the forest sector (Callaway *et al.*, 1999).

As was mentioned previously, five options were evaluated. Planting trees without rotation is intended for conservation, which is designated for rehabilitating critical areas of forest. Forest protection is intended for protecting forests from conversion to other uses and from harvesting, while planting trees with rotation is intended for reforesting degraded forests or non productive forests and for producing wood.

Data inputs were obtained from official or non-official reports and published references. Cost data were mostly taken from the proposed budget for the 2000 reforestation program issued by the office of reforestation, except for RSR, which was obtained through interviews with foresters at the DFW. It was indicated that the investment, and first year operation and maintenance cost for RSR were higher than RLR. The investment cost of RSR is US$ 400 per ha, while RLR was US$ 300 per ha, and the first year operation and maintenance cost for RSR was US$60 per hectare and US$ 12 per ha for RLR. Timber and fuel wood prices were estimated based on Bottomley's paper (2000). The detailed COMAP inputs for each option are presented in Appendix 1.3.

The analysis of land allocation for each option were based on the 2000 Reforestation Planning Program, proposed by the Office of Reforestation, and the Five-Year Plan for Forestry Sector, 2001-2002) prepared by the Department of Forestry and Wildlife, and the Ministry of Agriculture, Forestry and Fisheries. The plan states that 6 million hectares of degraded forestlands need to be rehabilitated between 2001 and 2005. Percent allocation for RSR, RLR, RFG and RLG were 51, 19, 22, and 8%, respectively.

1.4.2. Potential and Cost Effectiveness of Mitigation Options

Mitigation potential of the five options ranged from 43 to 141 tC/ha. RLG and FP have mitigation potential of more than 100 tC/ha, while the other three have less than 100 tC/ha (Table 1.3). In terms of investment cost, FP is the lowest (2.5US$/ha), while RSR is the highest (47US$/ha). Life cycle cost for sequestered carbon ranged from 0.28 US$/tC to 1.78US$/tC, while the net present value of benefit ranges from –0.77 to 4.66 US$/tC. Options that gave positive benefits were only RLR and RSR (from harvested wood). The others options gave negative benefits since no wood harvesting is allowed. Costs of carbon abatement of this study were slightly lower that the mean global cost. For low latitude regions, mean global cost for carbon abatement was between 2 and 7 US$/tC (Table 1.4).

Table 1.3: Comparison of the Five Mitigation Options

Mitigation Option	Mitigation Potential (t C/ha)	Initial Cost		PV of Cost		NPV of Benefit	
		$/tC	$/ha	$/tC	$/ha	$/tC	$/ha
RLR	120	0.29	35.4	0.41	48.8	0.05	6.0
RSR	43	1.10	47.2	1.78	76.2	4.66	199.8
RLG	141	0.18	25.4	0.28	39.2	-0.26	-36.4
RFG	92	0.28	25.4	0.43	39.2	-0.32	-29.1
FP	137	0.02	2.5	0.51	70.0	-0.77	-105.7

1.4.3. Mitigation Scenarios

In this study, three mitigation scenarios were proposed namely baseline scenario, potential scenario and mitigation scenario.

The baseline scenario is a scenario to evaluate mitigation potential of LUCF sector in the future if the rate of tree planting (sink enhancement) on degraded land is assumed to be the same as the historical planting rate and no efforts are made to protect the protection forest from being deforested.

The mitigation scenario is a scenario to evaluate mitigation potential of LUCF sector in the future if the rate of tree planting (sink enhancement) and efforts to protect the forest from deforestation follow government plans.

The potential scenario is a scenario to evaluate mitigation potential of LUCF sector in the future if all degraded land were reforested and efforts to protect the forest from deforestation were maximum.

Table 1.4: Global Potential and Costs (1995-2050)

Latitudinal Zone	Measure	C Sequestered (GtC)	Cost (US $/tC)	Total Cost (10^9 US$)
High	Forestation	2.4	8 (3-27)	17
Mid	Forestation	11.8	6(1-29)	60
	Agroforestry	0.7	5	3
Low	Forestation	16.4	7(3-26)	97
	Agroforestry	6.3	5(2-12)	27
	Regeneration	11.5-28.7	2(1-2)	
	Slowing deforestation	10.8-20.8	2(0.5-15)	44-97
	Total	**60-87**	**3.7-4.6 (1-29)**	**250-300**

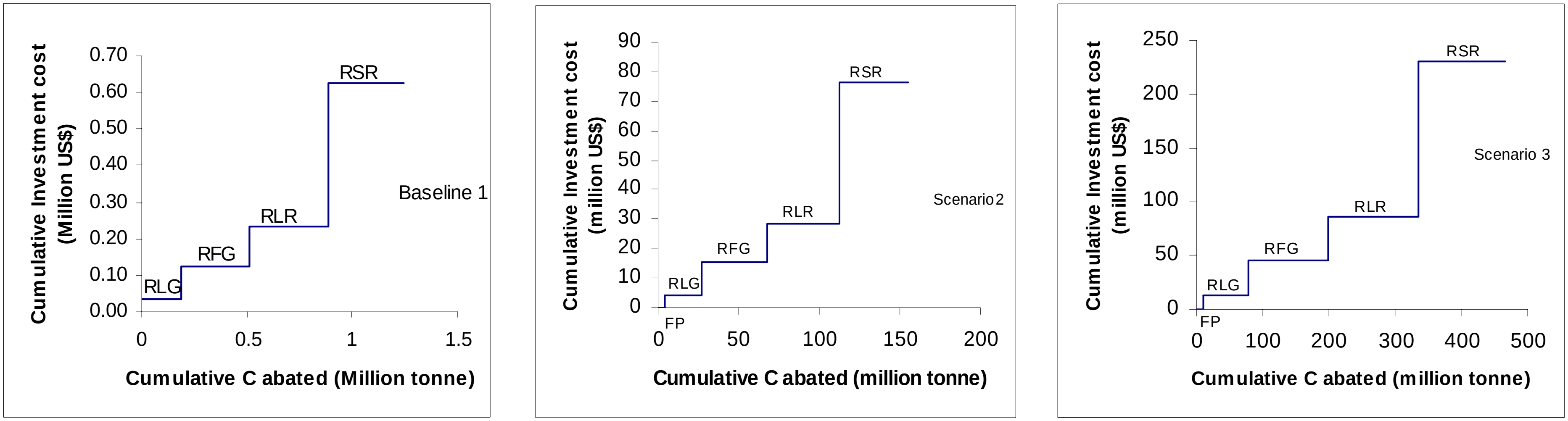
Source: Sathaye (1999).

Using the above assumption, under the **baseline scenario**, the total area that could be reforested in the next 30 years is approximately 16,320 ha based on the historical rate of reforestation of 544 ha/year (DFW. Statistics of Reforestation). Under the **mitigation scenario**, the total area that should be reforested is approximately 2 million ha since in the Second Five-Year Plan for the Forestry Sector (DFW), it was stated that the government target for reforestation was only 33% of the total degraded forestlands. The total degraded forest was estimated to be approximately 6 million ha. Total area of protection forest that can be protected from deforestation is approximately 33,791 ha. Under the **potential scenario**, the total area that should be reforested is 6 million ha and deforestation prevented should be approximately 70,182 ha. Figures for avoided deforestation in mitigation and potential scenarios were taken from Cambodia Forest Policy Assessment developed by World Bank/FAO/UNDP (1996; see Appendix 1.4 under Scenarios 2 and 3). Avoided deforestation of approximately 70,182 ha can be achieved under strict forest management policy. The total area allocated for the three scenarios as well as total carbon mitigation potential, investment cost, life cycle cost and net present value of benefit is presented in Table 1.5.

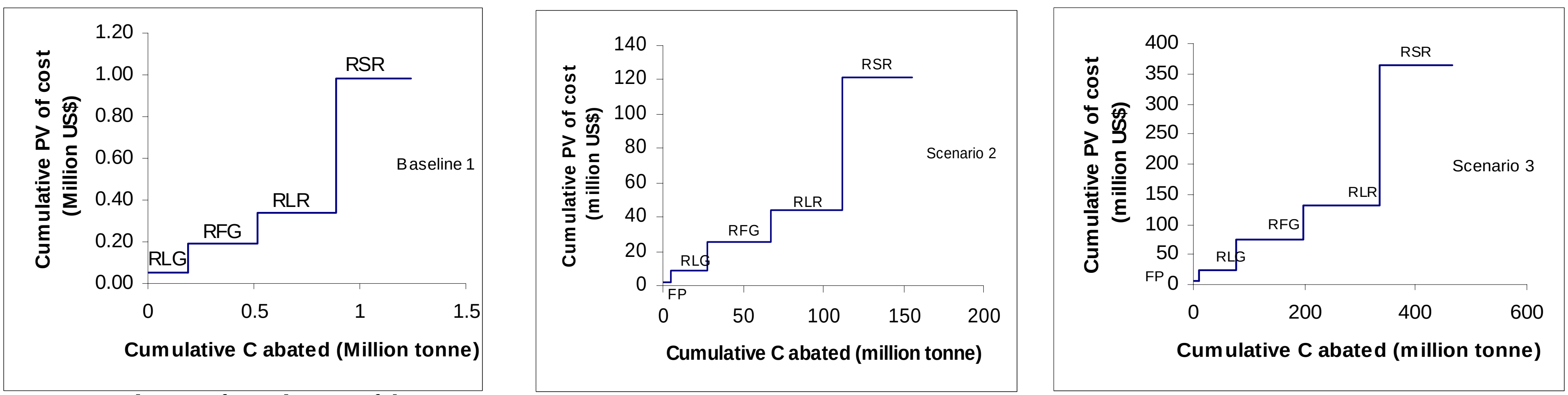
Table 1.5: Mitigation Potential, Investment Cost, Present Value of Cost and Net Present Value of Benefit of the 3 Scenarios

Mitigation Option	Mitigation Potential (t C/ha)	Land Available (ha)	Carbon Mitigation (t C)	Investment Cost (US$)	PV of cost (US$)	NPV of Benefit (US$)
Scenario 1: Baseline						
RLR	120	3,084	369,954	109,088	150,545	18,674
RSR	43	8,340	357,526	393,256	635,808	1,666,456
RLG	141	1,322	186,060	33,506	51,888	-48,063
RFG	92	3,574	328,815	90,589	140,291	-103,962
Total		**16,320**	**1,242,356**	**626,439**	**978,532**	**1,533,104**
Scenario 2: Mitigation						
RLR	120	374,900	44,965,788	13,259,030	18,297,835	2,269,700
RSR	43	1,013,620	43,455,139	47,797,983	77,278,771	202,547,952
RLG	141	160,672	22,614,528	4,072,416	6,306,719	-5,841,834
RFG	92	434,408	39,965,573	11,010,607	17,051,500	-12,635,993
FP	137	33,791	4,626,933	84,478	2,366,742	-3,570,247
Total		**2,017,391**	**155,627,961**	**76,224,514**	**121,301,567**	**182,769,578**
Scenario 3: Potential						
RLR	120	1,134,000	136,012,669	40,105,958	55,347,353	6,865,396
RSR	43	3,066,000	131,443,253	144,579,501	233,753,089	612,667,730
RLG	141	486,000	68,404,500	12,318,258	19,076,585	-17,670,398
RFG	92	1,314,000	120,888,000	33,304,921	51,577,434	-38,221,395
FP	137	70,182	9,609,823	175,455	4,915,561	-7,415,157
Total		**6,070,182**	**466,358,244**	**230,484,093**	**364,670,022**	**556,226,175**

Based on the data from Table 1.5, it can be estimated that total carbon that can be abated under the baseline, mitigation and potential scenarios are approximately 1.24, 155.6 and 466.4 million tonnes carbon respectively, while the cumulative investment required are approximately 0.63, 76.22, and 230.48 million US$ and the life cycle costs are approximately 0.98, 121.30 and 364.67 millions US$, respectively and cumulative net present value of benefit are approximately 1.53, 182.77 and 556.23 millions US$, respectively (Figure 1.3).

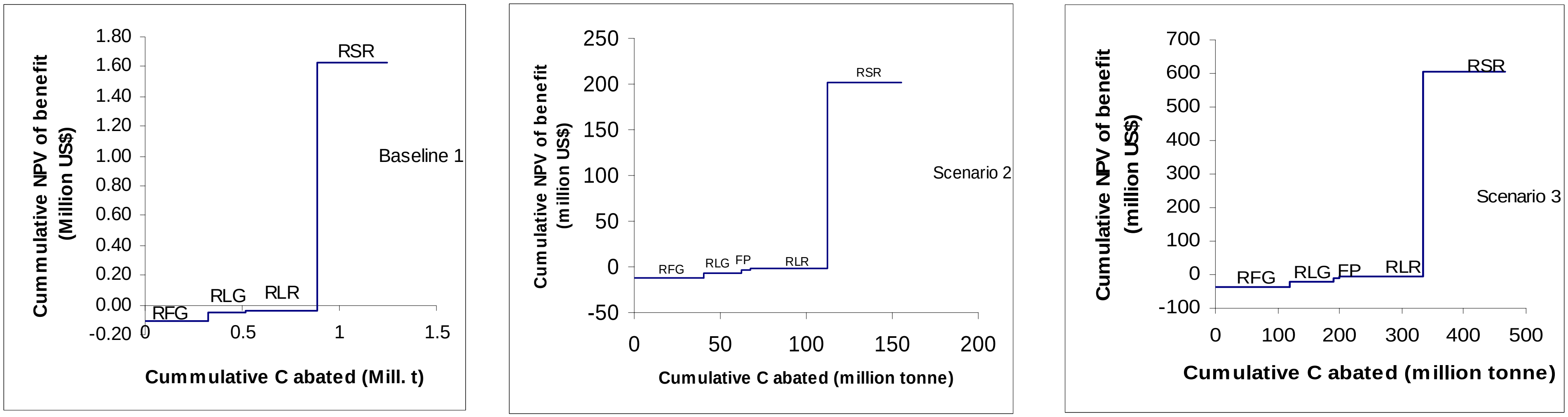


Cumulative Investment of the 3 Scenarios



Cumulative Life Cycle Cost of the 3 Scenarios

Figure 1.3: Cumulative Investment Cost, Cumulative Life Cycle Cost and Cumulative Net Present Value of Benefit of the 3 Scenarios



Cumulative Net Present Value of Benefit of the 3 Scenarios

Figure 1.3 (cont.): Cumulative Investment Cost, Cumulative Life Cycle Cost and Cumulative Net Present Value of Benefit of the 3 Scenarios

1.5. Conclusion and Recommendations

The five mitigation options have been evaluated, namely reforestation with short and long rotation (RSR and RLR), reforestation without rotation using fast growing and slow growing species (RFG and RLG) and forest protection (FP). The mitigation potential of the five options ranged from 43 to 141 tC/ha, where RLG, RLR and FP have mitigation potentials of more than 100 tC/ha, while the other two were less than 100 tC/ha.

Investment costs required to implement the five options ranged from 2.5US$/ha (for FP) to 47US$/ha (for RSR), while the life cycle cost required for sequestering one tonne of carbon ranged from 0.28 US$ to 1.78US$. The net present value of benefit of the five options ranges from -0.77 to 4.66 US$/tC. Options that gave positive benefits were only RLR and RSR (from harvested wood).

The total areas required to implement the five options under baseline, mitigation and potential scenarios are 16,320; 2,017,391 and 6,070,182 ha, respectively. The total carbon that can be abated under these three scenarios are approximately 1.24; 155.6 and 466.4 million tonnes, respectively. The total investment costs are 0.63, 76.22, and 230.48 million US$ respectively, while life cycle costs are 0.98, 121.30 and 364.67 million US$, respectively, and total benefits are 1.53, 182.77 and 556.23 million US$, respectively.

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APPENDICES

Appendix 1.1: Estimated Timber Trade from Illegal Logging by Province (m^3 of Roundwood Equivalent)

Province	Concession Operations	Collection of Illegal Fellings	Illegal Domestic and Export in Log Form	Illegal Sawnwood Domestic and Exports	Total Roundwood Equivalent	Total Roundwood Equivalent (percent)
Ratanakiri	447		300,000	12,800	313,247	7
Stung Treng		100	110,000	96,000	206,100	5
Kratie	105,900	183,800	140,000	192,000	621,700	15
Mondulkiri			14,500	19,200	33,700	1
Kampong Thom	68,400	25,200	75,000	57,556	226,156	5
Kampong Cham			45,000	66,667	111,667	3
Kampong Speu			10,000	240,000	250,000	6
Kampong Som	15,400			128,000	143,400	3
Kampot				102,222	102,222	2
Koh Kong	58,300	300	15,000	1,392,000	1,465,600	35
Battambang			250,000	200,000	450,000	11
Bantey Meanchey				88,889	88,889	2
Pursat			70,000	96,000	166,000	4
Preah Vihear			65,000	0	65,000	2
Siem Riep				0	0	0
Others		3,600		0	3,600	0
Total	248,447	213,000	1,094,500	2,691,333	4,247,280	
Percent	6	5	26	63		100

Source: World Bank (1999).

Appendix 1.2: Summary of Statistics for Existing Concessions

No.	Name of Company	Province	Country-Origin	Area (ha)
1	GAT International Co., Ltd.	Koh Kong; Pursat	Malaysia	215,720
1A	GAT International Co., Ltd.	Kampong Thom, Kratie	Malaysia	149,780
2	Colexim Enterprise	Kampong Thom	Cambodia/ Japan	147,187
3	Casotim Co., Ltd.	Kratie	Cambodia/ Russia	131,380
4	SL International Ltd.	Kratie, Kampong Cham, Modulkiri	Malaysia	467,484
4A	SL International Ltd.	Kampong Speu, Koh Kong	Malaysia	298,598
5	Mieng Ly Heng Investment Co., Ltd.	Kampong Thom, Preah Vihear, Kampong Cham	Cambodia	198,500
6	Long Day-Machinery-Industry Co., Ltd.	Kampot, Kampong Speu	Taiwan	98,000
7	Pheapimex Fuchan Cambodia Co., Ltd.	Kratie, Stung Treng, Preah Vihear, Kampong Thom	Taiwan	358,725
7A	Pheapimex Fuchan Cambodia Co., Ltd.	Stung Treng, Ratanakiri	Taiwan	350,000
8	Lansong International Co., Ltd.	Preah Vihear	Taiwan	132,000
9	Hero Taiwan Company	Ratanakiri	Taiwan	60,150
10	King Wood Industry Pte, Ltd.	Kratie, Stung Treng, Mondulkiri	Taiwan	301,200
11	Cambodia Cherndar Plywood Mfg. Co., Ltd.	Preah Vihear	Taiwan	103,300
12	Sam Rong Wood Industry Pte. Ltd.	Siem Reap	Cambodia	200,050
13	Everbright CIG Wood Co., Ltd.	Kratie, Stung Treng	China	136,376
14	Super Wood IPEP Ltd.	Pursat, Kampong Speu	Malaysia	94,419
15	Timas Resources Ltd.	Kampong Cham, Kratie, Preah Vihear	Singapore	161,450
16	Silveroad Wood Products Ltd.	Koh Kong, Pursat	China	215,460
16 A	Silveroad Wood Products Ltd.	Koh Kong	China	100,000
17	You Rysaco Company	Pursat, Battambang	Cambodia	214,000
18	TPP Cambodia Timber Product PTE, Ltd.	Siem Reap, Preah Vihear, Pursat	Thailand	395,900
19	Voot Tee Peanich Import Export Co., Ltd.	Koh Kong	Cambodia	63,050
20	Cambodia Timber Product Pty Ltd.	Kampot	Cambodia	34,924
Total				4,627,653

Source: Cambodia Sustainable Forest Management Project (TA 3152-CAM)

Appendix 1.3: Data Input for Assessment of Mitigation Activities in Forestry Sector

	RSR	RLR	RSG	RLG	FP
Investment cost	400 (1)	300 (2)	215 (3)	215 (3)	2.5 (4)
O & M cost ($/ha)					
Year-1	60 (1)	12 (3)	12 (3)	12 (3)	0.5 (4)
Year-2	40 (3)	12 (3)	12 (3)	12 (3)	0.5 (4)
Year-3	12 (3)	12 (3)	12 (3)	12 (3)	0.5 (4)
Year-4	12 (3)	12 (3)	12 (3)	12 (3)	0.5 (4)
Year-5	12 (3)	12 (3)	12 (3)	12 (3)	0.5 (4)
Monitoring/protection costs ($/ha/year)	0.5 (3)	0.5 (3)	0.5 (3)	0.5 (3)	
Discount rate (%)	10%	10%	10%	10%	10%
Rotation period/cumulative period (Year)	10 (5)	30 (5)	20 (5)	35 (5)	
Mean annual increment (tB/ha) (6)	15.0	10.0	10.0	7.5	
Soil carbon change (tC/ha/year) (7)	1.00	0.75	0.50	0.5	0.5
Amount of decomposing carbon (t C/ha/harvest) (8)	20	34	N/A	N/A	12
Decomposition period (year) (10)	4	4	N/A	N/A	4
Amount of carbon stored in the product (tC/ha/harvest)	47	101	N/A	N/A	N/A
Timber (log) product (% of MAI) (11)	60%	60%	0%	0%	
Timber (log) price ($/t)	56 (12)	161 (13)	0	0	
Annual fuel wood production (% of MAI) for young trees (14)	5%	7%	10%	10%	
Annual fuel wood production (% of MAI) for old trees (15)	10%	15%	10%	10%	
Fuel wood price ($/t) (16)	30	30	30	30	
Non-timber output (resin) (t/ha/yr)	0	0	0	0	0
Non-timber (resin) price ($/t)	0	0	0	0	0

Source: [1] & [2] estimated based on interview with forester; [3] estimated based on budget proposed for reforestation in 2000; [4] estimated based on Camille Bann 1997; [5] assumption; [6] assumption; [7] assumption; [8] estimated from rotation period (Yr.), mean annual increment [MAI (tB/yr/ha)], carbon density (%), timber product (% of MAI), fuelwood product at old age (%MAI); [9] assumption; [10] estimated from rotation period (Yr.), mean annual increment [MAI (tB/yr/ha)], carbon density (%), timber product (% of MAI), fuelwood product at old age (%MAI); [11] assumption; [12] estimated from WB/FAO/UNDP 1996; [13] estimated based on Ruth Bottomly 2000; [14] assumption; [15] assumption; [16] estimated based on FAO Fuelwood Flow Study of Phnom Penh, Cambodia.

Appendix 1.4: Change in Forest Types (1993-2010) in Area (ha)

Forest Types	1993			Scenario 1 (2010)			Scenario 2 (2010)			Scenario 3 (2010)		
	Total	Protected Forests	Unprotected Forests	Total	Protected Forests	Unprotected Forests	Total	Protected Forests	Unprotected Forests	Total	Protected Forests	Unprotected Forests
Dry land forest	**10,568,600**	**2,862,300.00**	**7,706,300**	**8,771,938**	**3,492,972**	**6,396,229**	9,258,529	**2,862,300**	**6,396,229**	**9,913,565**	**2,862,300**	**7,051,265**
Evergreen	4,763,300	1,797,500.00	2,965,800	3,953,539	1,491,925	2,461,614	4,259,114	1,797,500	2,461,614	4,511,207	1,797,500	2,713,707
Coniferous	9,800	9,800.00	0	8,134	8,134	0	9,800	9,800	0	9,800	9,800	0
Deciduous	4,301,200	1,055,000.00	3,246,200	3,569,996	875,650	2,694,346	3,749,346	1,055,000	2,694,346	4,025,273	1,055,000	2,970,273
Mixed	977,300	0.00	977,300	811,159	0	811,159	811,159	0	811,159	894,230	0	894,230
Secondary	517,000	0.00	517,000	429,110	0	429,110	429,110	0	429,110	473,055	0	473,055
Edaphic forest	**715,600**	**715,600.00**	0	**593,948**	**593,948**	0	**715,600**	**715,600**	**0**	**715,600**	**715,600**	**0**
Flooded	370,700	370,700.00	0	307,681	307,681	0	370,700	370,700	0	370,700	370,700	0
Flooded secondary	259,800	259,800.00	0	215,634	215,634	0	259,800	259800	0	259,800	259,800	0
Mangrove	85,100	85,100.00	0	70,633	70,633	0	85,100	85,100	0	85,100	85,100	0
Total forests	11,284,200	3,577,900	7,706,300	9,365,886	2,969,229	6,396,229	9,974,129	3,577,900	6,396,229	10,629,165	3,577,900	7,051,265

Notes: Scenario 1 = business as usual, Scenario 2 = focus on protected areas, Scenario 3 = commitment to reform.
Source: FAO, Cambodia Land Cover Atlas (1994b) and Mission Projections. In World Bank/FAO/UNDP, 1996.

Greenhouse Gas Mitigation Analysis

Section 2

AGRICULTURE SECTOR

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2.1. Introduction

Greenhouse gases (GHGs) emissions from the agricultural sector, include CH_4, NOx, N_2O and CO. The emissions are produced by several sub-sectors such as livestock, rice fields, agricultural soils and burning of agricultural residues and grassland (Table 2.1). Each sub-sector emits different forms and magnitudes of GHG. Livestock and rice fields are the major source of CH_4 (78%), while agricultural soils are the main source of N_2O.

Emissions of GHGs from domestic livestock in Cambodia mostly come from enteric fermentation and small amounts from manure management in the form of CH_4. The 1994 inventory has indicated that only non-dairy cattle[2] have emitted 184.79 Gg equivalent to 48.14% of the total emissions from this sector. Economic and population growth has increased consumption of meat and eggs, for example an increase of 6.52% in 1998 (agriculture Development Plan, Long, Medium and Short Term- 1999 to 2010).

Rice fields are the second greatest contributor to CH_4 emissions in the country amounting to 150.40 Gg or 29.91% of national CH_4 emissions (1994 inventory). Lowland rainfed rice fields emit the highest rate contributing to 103.7Gg (68.9%) whereas irrigated rice fields contribute to approximately 31.1% of the total emissions from rice fields. Cambodians use rice as the staple food with consumption of approximately 162 kg/capita/year. With an average population growth of 2.49%, substantial amounts of rice will be required in the future and this will lead to increases in CH_4 emissions. It is predicted that the increasing rate of CH_4 emissions will be proportional to the increasing rate of rice production.

Considering the above facts, efforts to reduce emissions from the agriculture sector, in particular methane emissions, are important. Technologies being used should meet at least the following criteria: environmentally sound, socially acceptable and economically viable. This study evaluated the cost effectiveness of methane emissions reduction technologies for rice paddy and their appropriateness according to the criteria mentioned above. An evaluation of mitigation options for livestock was not performed due to a lack of data.

Table 2.1: Summary of GHG and Precursors Emissions from Agriculture (Gg)

Source	Emissions Type				CO_2 Equivalent
	CH_4	N_2O	NOx	CO	
Domestic livestock	184.8	3.9			5,084.1
Rice cultivation	150.4				3,158.4
Grassland burning	2.0	0.0	0.9	51.9	49.1
Agricultural residue burning	2.1	0.1	1.8	43.9	59.4
Agricultural soil		7.1			2,209.2
Total	**339.3**	**11.1**	**2.7**	**95.8**	
Total CO_2 Equivalent					**10,560.2**

2.2. Agriculture Practices in Cambodia

Rice farming practices vary considerably between the rainfed lowland, upland, deepwater, and irrigated areas. In rainfed lowland and deepwater, farmers usually start preparing their land for planting in April and May of each year and harvesting in November-January, whereas in irrigated areas, farmers usually start planting in November-January and harvesting in April-May. Some farmers commonly use farmyard manure before planting. Application rate of manure varies depending on its availability, it normally

[2] In Cambodia there is no dairy industry so all ruminants are classified as non-dairy cattle in this study.

ranges from 0.20 to 2.50 tonnes per hectare (Lando and Solieng, 1994a). This practice may have positive impact on both production and methane emissions.

When rain is sufficient, farmers normally plough their land for leveling twice and harrow once or twice. The nursery is normally established near to a water supply and sometimes close to the farmers' house. The area used for nursery establishment is approximately 15-25% of the total farm. In some provinces such as Battambang, Pursat and Banteay Meanchay, direct seeding is practiced. Farmers broadcast seeds directly after plowing the soil once or twice. The labor involved in establishing and managing the nursery plus transplanting is thereby eliminated. However, weed problems occur if this technique is used. Farmers often plow the crop once six to eight weeks after emergence to kill the weeds. From some studies, it was indicated that this system also could reduce methane emissions (Pawitan *et al.* 1998).

Preparation of land for deep-water rice commences immediately prior to the start of the wet season and after burning stubble from the previous crop. Plowing follows immediately. The common practice is two plowings and one harrowing followed by broadcasting of dry seed at a rate of between 120 –150 kg/ha. However, if the rainy season commences a little late, some farmers may broadcast the rice seed and plow it in or broadcast over single plowed soil. The fields are not bounded and weed incidence is prolific. Animals regularly graze the field prior to flooding. Some farmers weed their fields but few apply herbicides or spray pesticides. Harvesting is conducted after the floodwaters recede by cutting the stems immediately below the panicle. The sheaves are returned to the village for threshing. Fertilizers are rarely applied to deepwater rice fields, thereby limiting nitrous oxide emissions.

Most dry season rice is cultivated in flood recession areas. As such, it receives regular nutrient supplementation from siltation and fertilizer is applied in the form of urea as a top dressing. The first available fields are utilized as nurseries. From these, paddies from succeeding recession areas are transplanted. Water is pumped back up the profile from rivers and recession ponds. Modern, non-photoperiod sensitive varieties are grown and recommended practices for these are followed. Transplanting is spread over the November to February period and in some areas supplementary pump irrigation is provided to the crop towards the end of the dry season or beginning of the wet season (Nesbett, 1996).

Spot weeding of rainfed fields is a common practice and farmers regularly drain or rebund their fields during the wet season for improved weed control. Harvesting is by a hand held sickle and sheaths are regularly stacked on bunds to dry prior to threshing. Once dried, the sheaths are generally transported by ox-cart. The rice straw is heaped in a pile (usually around a post) to be fed to animals during the wet season when there is little pasture to graze. In addition, some farmers burn off the stubble during the first quarter of the year to assist land preparation and kill off residing pests and diseases. This practice decreases the quantity of roughage for grazing animals. At the onset of the first rains, germinating weeds increase the availability of green feed in rainfed and deepwater rice fields. Reasonable quality legume pasture also develops on the bunds and other ground which are not flooded in the wet season. There is potential for improving quality of this pasture as a source of animal feed with the application of phosphorus and introduction of improved species (White *pers comm*). This practice may reduce methane emissions from livestock per unit weight. At present there is no data available in regard with the impact of improving pasture quality as animal feed on methane emissions.

The above facts indicate that some of farmers' practices have already followed GHG mitigation technology practices. There is a need to extend the technologies to other regions in the country, in order to give positive benefits not only to the farmers but also to the environment.

2.3. Taxonomy of Mitigation Options in Agriculture Sector

The 1994 National GHG Inventory showed that livestock and rice paddies are major contributors to the total methane emissions of the country. There are many mitigation options available to reduce the methane emissions from these two sectors. Brief descriptions of options that can be used follow:

2.3.1. Enteric Fermentation

The mitigation options that can be used to reduce methane emissions from ruminants are: giving supplemental feed to the animal such as mineral blocks molasses urea blocks, urea treatment of straw, and chemical feed treatment. The mitigation potential of these options varied between 3.8 and 27 kg CH_4/animal/year. Urea treatment of straw, which improves digestibility by 25% is considered in many developing countries. The mitigation potential of this option ranges between 3.8-8.3 kg/animal/year. An additional benefit is that all these mitigation options are estimated to lead to increased milk yield.

2.3.2. Manure Management

The use of manure for producing energy (biogas production) has been considered by some Asian countries such as Indonesia, RoK, India and China. CH_4 emissions reduction was estimated to be in the range of 2-39kg/animal/ year. Biogas produced can be used as fuel for cooking, substituting fuelwood or kerosene, or as feedstock for electricity generation at a decentralized scale. This leads to further GHG emissions reduction and can also improve the quality of life for rural women.

2.3.3. Rice production

Mitigation options for rice which are commonly used are intermittent drainage, use of low CH_4 emitting varieties, use of composted organic matter and ammonium sulfate, dry seed nurseries and zero tillage. Intermittent drainage (3-4 times/season) creates aerobic periods which suppress methane producing bacteria. This has the potential to reduce CH_4 emissions by up to 50% (50-100kg/ha/year). Use of composted organic matter, one of the easiest options is considered by Philippines and China and has a mitigation potential of 48-128 kg/ha/year. Some of the mitigation options such as biogas, intermittent drainage, urea treatment of straw and use of composted organic matter are defined as "win-win" strategies. Low methane emitting cultivars may need large-scale field trials by farmers before adoption of the varieties.

In summary, mitigation options that have been evaluated by most Asian countries as well as their features and the mitigation potential are given in Table 2.2.

Table 2.2: Experiences of Mitigation Options from ALGAS Countries

Category and Type of Mitigation Options	Countries Analyzing the Option	Features	Mitigation Potential, kg/ha or Animal/yr[1]	Impact on Yield (% Increase or Decrease) [2]
LIVESTOCK: CH_4 mitigation from Enteric fermentation				
Providing mineral blocks/MNB	Indonesia, China	10-30% increased in milk yield (only for dairy cattle), enhances protein use efficiency enhances feed conversion efficiency	15.4 (3.8-27)	+30 % milk in 2 years +(16-50%) milk
Molasses-Urea block	Indonesia, Bangladesh, Myanmar, India	Increase feed conversion efficiency, 25% in crease in milk yield, CH_4 reduce by 27%, 60% increase in animal productivity.	14.0	N/A
Urea treatment of straw	China, Indonesia, Myanmar, Vietnam	Rice straw soaked in 2% urea for 15d, improve digestibility up to 25%, 15-20% achievable in field, milk yield increase by 20-30%	6.1 (3.8-8.3)	N/A
Chemical/Mechanical feed treatment	Vietnam, R. of Korea	Improve digestibility by 5%, enhances weight gain (6kg/yr), 10-30% reduction in CH_4.	10 (5-15)	N/A
Genetic Improvements	Indonesia	10% reduction in CH_4 (IPCC), 160% increase in milk yield.	8.3	+157% milk
LIVESTOCK: CH_4 Emissions from Manure				
Biogas plants	Indonesia, China, R. of Korea	70% reduction in CH_4 emissions (where lagooning is practiced).	2-39	Source of energy, bio-fertilizer and other purposes.

Table 2.2 (cont.)

RICE PADDY: CH_4 emissions				
RICE PADDY Intermittent drainage(3-4times/ season)	VN, Indonesia, India, China, Philippines, R. of Korea, Pakistan,	Creates aerobic periods and suppresses methane bacteria - up to 50% reduction in CH_4 - applicable to flooded rice only.	75 (50-100)	5.4
Low CH4 emitting varieties	Philippines, China	Transports less CH_4 from soil to air, Tested in few countries only, e.g.IR-64	3.7-3.8	N/A
Using composted organic matter	China, Philippines	Estimated at 50% CH_4 reduction (NR)	48-128 (24-62%)	N/A
Direct seeded nursery	China	Reduce period of flooding.	14.4 (5.8-23)	4.3
No tillage	Indo	Bring about 12% reduction in CH_4 emissions.	22.9	-8.4
Ammonium sulfate usage	Philippines, Indo	Competes with methane bacteria and suppresses CH_4 production by about 20% (IPCC)	5.5 (1-10)	6.7

Source: [1]Ravindranath, (1995), [2]Pawitan et al. (1998).

2.4. Assessment of GHG Mitigation Options

As mentioned previously, the mitigation options evaluated for the agriculture sector only covered rice paddies. The methodology used followed the guidelines provided by UNEP (Halnsen et al., 1997). The steps of the analysis are described below.

2.4.1. Methodology

The steps of the analysis to evaluate the cost effectiveness of mitigation options are as follows (Halnsen *et al.* 1997):

1. Estimation of cost for implementing the mitigation options. Cost for implementing the options was estimated using the following formula:

$$TC_m = \sum_{j=1}^{n_I} c_j * X_j$$

Where m denotes mitigation, c_j is cost paid for inputs j^{th} (labors, fertilizers, seeds etc.) and X_j is amount of inputs j^{th} used. In the long run, in terms of land rent (equal to present value of cost) from the use of a piece of land (LR), over an infinite time horizon is equivalent to:

$$LR_m = \sum_t^{\alpha} TC_m * (1+r)^{-t}$$

On an annual basis using a large value of T, t=1, 2, 3, ……, T; equal to annualized value of cost (annualized land rent, *ALR*), the above term can be expressed as follows:

r is the annual real discount rate (adjusted for inflation).

$$ALR_m = r * LR_m * (1 - (1 + r)^{-T})^{-1}$$

2. Estimation of total benefit of the mitigation options. Equation to express benefit (*TR*) on an annual basis is:

$$B_m = \sum_{i=1}^{n_O} [p_i * Q_i] - \sum_{j=1}^{n_I} [c_j * X_j]$$

p_i is price of product i^{th} and Q_i amount of good product i^{th}. Similar to total cost, in term of land rents the annualized value of benefit is also calculated using the same formula.

3. Estimation of mitigation cost. The mitigation costs, MiC, are measured in terms of the difference in profits between two scenarios -a baseline case and a mitigation scenario. This is expressed for a single period in the future as (reflect short term cost-effectiveness of mitigation option):

$$MiC = B_m - B_b$$

Where the subscript, *m*, indicate the mitigation scenario and, b, indicates the baseline case. In terms of land rent, ALR for baseline case is also calculated using similar formulas described above, therefore, the annualized value of *MiC* is (reflects present cost-effectiveness of mitigation option, further off in the future, says 2030 or 2020):

$$MiC = ALR_m - ALR_b$$

Furthermore, the cost effectiveness ratio (CER) of a single option for a period in the future is expressed as

$$CER_t = MiC_t / \partial E$$

Where ∂E is total change in emissions associated with the mitigation option expressed in CO_2-equivalent.

4. Development of CERI (*Carbon Emissions Reduction Initiative*) curve. The CERI curve is developed by arranging the CER of mitigation options from the lowest to the highest cost and plotting the CER (vertical axis) versus the CO_2 equivalent emissions reduction (horizontal axis) for each mitigation option. This curve is developed for the two specific periods in the future.

5. The impact of implementation of mitigation options of overall methane emissions reduction and rice production. To estimate the impact of implementing mitigation in a given rice growing area the following steps of analysis were carried out. First define the rice growing area to which the mitigation options are being applied and multiply the planted area with the expected productivity for each season for the given mitigation options to yield rice production under mitigation. This estimated rice production was then summed with rice production from non-mitigated rice growing area (areas which are not treated with the mitigation options). A similar approach was also applied to estimate total CH_4 emissions from rice growing areas under both mitigation and baseline scenarios.

2.4.2. Feature of Mitigation Options Being Evaluated

In this study, the mitigation options being evaluated are:

1. Intermittent irrigation applied only in dry season rice (DSInt);

2. Direct seeded applied in both dry and wet seasons (DSDirect and WS Direct);

3. Organic matter management applied in both seasons (DSManure and WSManure); and

4. Zero tillage applied in both seasons (DSZero and WSZero).

Most of the emission factors used in the analysis were taken from studies carried out in Indonesia (Makarim *et al.*, 1996; Makarim and Setyanto, 1998; Husin and Murdiyarso, 1995), since such information was not available in Cambodia. The feature of each option is given in Table 2.3. All costs associated with the options were derived from Nesbett (1996) and Rickman *et al.* (1995).

Table 2.3: Feature of Mitigation Options Evaluated in the Study

No	Option	Features	Percent of Methane Emissions Reduction from Baseline
1	Intermittent Irrigation	The Baseline field is flooded continuously while in the Mitigation field is dried for a certain interval (3-4 times per seasons). This method can save 50% of water from usual method. This option is only possible in the dry season rice (irrigated rice). In this study it is assumed that the baseline used traditional system while the mitigation used improved system (Nisbett, 1996). It is assumed that yield in intermittent system increased by 5.4% (Pawitan *et al.*, 1998)	29.8% (Makarim et al., 1996).
2	Direct seeding	In the baseline scenario, seed is broadcasted first in the nursery and then transplanted, while in the mitigation scenario the seeds are broadcast directly to the field (save 4 person days). The seed requirement for direct seeded is more than transplanted system. Direct seeded needs 130 kg seeds/ha, while transplanted needs 80 kg seeds/ha (Rickman et al, 1995). But direct seeded does not require labor for transplanting. Labor for broadcasting the seeds is 3000 Riel/ha (Nesbitt, 1996). This can be applied in both WS and DS rice. In this study, the baseline used traditional system, while the mitigation scenario used improved system. Yield of improved system is 2 t/ha, while the traditional system is 1.3 t/ha. Price of seed in the improved and traditional systems are 800 and 368 Riel/kg respectively (Nesbitt, 1996). Yield was assumed to increase by 4.3% (Pawitan *et al.*, 1998). This option can only be applied to dry season rice.	19.7% (Makarim et al., 1996)

Table 2.3 (cont.)

3	Organic matter management	In the baseline scenario, the amount of manure applied was 5 carts (approx. 0.6 t/ha) while 20 carts (approx. 2.5 t/ha) were applied in the mitigation scenario. For DS rice, yield with less manure was 2.7 t/ha and more manure 3.3 t/ha. For WS, the yields were 1.3 and 2.0 t/ha respectively (Nesbitt, 1996). However due to manure application, the yields were assumed to increase by 6.9% in both seasons (based on Makarim and Setiyanto. 1998). This option can be done in both dry season and wet season rice. The cost for manure was assumed to be zero, since most of farmers can get manure in the village for free. Yield was assumed to increase by 6.8%.	13.3 (Estimated based on Makarim and Setiyanto, 1998).
4	Zero Tillage	In the baseline scenario, tillage is practiced while in zero tillage, there is no land preparation. Again in this study, it is assumed that the baseline used traditional system while the mitigation used improved system (Nisbett, 1996). This option can be done in both dry season and wet season rice. The yields were assumed to decrease by 10.8% for DS rice and 8.4% for WS rice (based on Makarim and Setiyanto, 1998).	12.2 (Makarim et al., 1996)

Note: In this analysis, the reference for EF used are 4.85 kg/ha/day (Continuous flooding; Husin and Murdiyarso, 1995). Variable cost and establishment cost used in this analysis was based on Nisbett (1996).

2.4.3. Result of Analysis

Mitigation Potential and Cost Effectiveness. Using the mitigation potential provided by studies conducted in Indonesia (Pawitan et al., 1999), it was found that all options evaluated in this study gave positive benefits which ranged from 10 to 71US$/ha (Table 2.4). In terms of methane reduction, the incremental benefit range between 116 and 774 US$/t$CH_4$ or equivalent to approximately 5.5 and 36.8 US$/t$CO_2$-Eqv. This analysis suggested that manure application gave the highest benefit not only to the increase in farmer income but also on methane emissions reduction. This type of option is defined as win-win option.

In general, it was found that the incremental benefit per hectare increases exponentially with potential of emissions reduction while incremental benefit per tonne of methane decreases exponentially with the mitigation potential (Fig. 2.1).

Table 2.4: Comparison of Seven Options

No.	Options	Mitigation Potential	Incremental Benefit (MiC)	
		(kg CH4/ha)	US$/ha	US$/t CH_4
1	Dry Season Intermittent	304	71	233
2	Dry Season Directed seed	121	69	574
3	Dry Season Manure	71	46	651
4	Dry Season Zero	86	10	116
5	Wet Season Direct	108	55	514
6	Wet Season Manure	66	51	774
7	Wet Season Zero	74	45	607

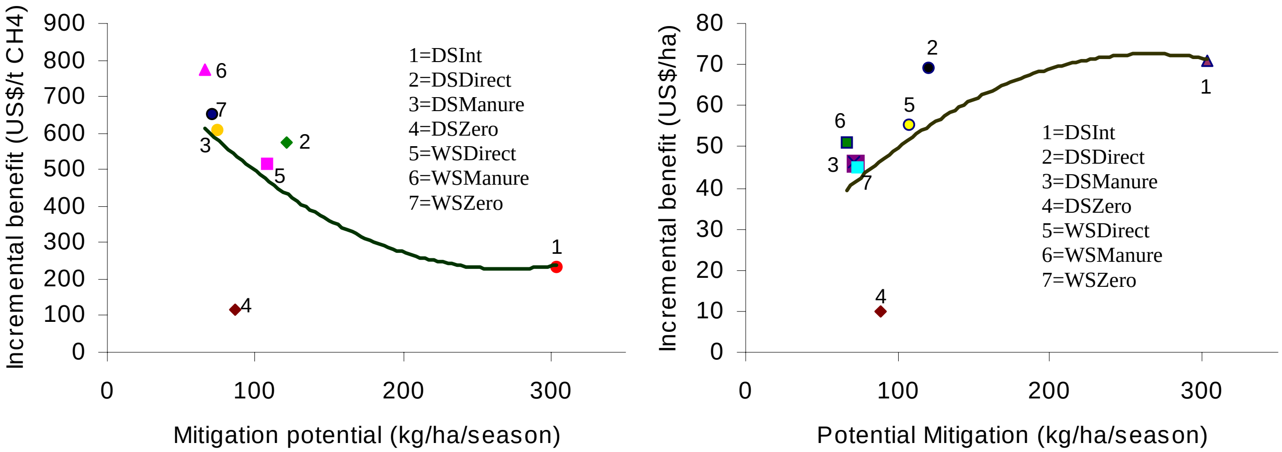

Figure 2.1: Relationship between Incremental Benefit (MiC) and Mitigation Potential

Prioritizing options is an important step to be taken before implementation. Options which have relatively higher scores for most of the attributes used in ranking the options should be the first priority option. There are several attributes that can be used for ranking the options. Some of the attributes used in this study are:

1. Profitability;
2. Yield;
3. Potential of CH_4 emissions reduction;
4. Applicability; and
5. Social acceptability.

In the ranking process, each attribute should be weighted following the relative importance of the respective attributes. In this study, the weight value used for each attribute is presented in Table 2.5. Profit is considered to be the most important attribute since this will have significant impact to the acceptability of the option by farmers. If the option is not profitable, farmers may not be willing to accept the option. Yield is the second most important attribute since Cambodia is expected to be a rice exporting country. Preferable options would be an option that could reduce methane emissions and increase yield. The remaining attributes have the same weights.

Based on these attributes, each option was evaluated and it was indicated that organic matter management has the highest weighted score, the most potential option for Cambodia, and followed by intermittent, direct seeded and zero tillage (Table 2.5). In this study, this score is used to determine the area allocated for implementing the options.

Table 2.5: Weights and Score of the Mitigation Options

No		Options	Profit	Yield	Mitigation potential	Applicability	Acceptability	Total Score
Weight Values			0.4	0.3	0.1	0.1	0.1	1
1	DS	DSInt	8.2	9.4	10.0	6.0	5.0	8.20
2	DS	DSDirect	5.3	10.0	4.0	8.0	6.0	6.90
3	DS	DSManure	10.0	6.9	2.3	10.0	10.0	8.32
4	DS	DSZero	1.2	2.9	2.8	7.0	3.0	2.63
5	WS	WSDirect	4.8	9.5	3.5	8.0	6.0	6.53
6	WS	WSManure	8.7	8.3	2.2	10.0	10.0	8.20
7	WS	WSZero	5.2	6.4	2.4	7.0	3.0	5.24

In this study, two mitigation scenarios were used. The first scenario is that the options be applied to all rice growing areas. In this regard, the scenario was defined as Potential scenario. The second scenario was intended to reduce methane emissions from the agriculture sector by approximately 10% from the baseline, thereafter it was defined as the Mitigation scenario. The rice growing areas allocated for each option according to the two scenarios is given in Table 2.6. This study suggested that in order to reduce 10% of methane emissions from agriculture sector, the total area that needs to be allocated for implementing the seven options was approximately 424,000 ha (20% of total rice growing area).

Table 2.6: Area Allocated for Each Option for Potential and Mitigation Scenarios

No.	Options	Score	Land Allocation under Potential Scenario (Hectares)	Land Allocation under Mitigation Scenario (Hectares)
1	Dry Season Intermittent	8.20	76,000	16,000
2	Dry Season Directed seed	6.90	64,000	33,000
3	Dry Season Manure	8.32	77,000	68,000
4	Dry Season Zero	2.63	24,000	18,000
5	Wet Season Direct	6.53	627,000	69,000
6	Wet Season Manure	8.20	786,000	140,000
7	Wet Season Zero	5.24	503,000	80,000
	TOTAL		**2,158,000***	**424,000**

*MAFF, 1999-2000 Agricultural Statistics.

The curve of carbon emissions reduction initiative (CERI; Figure 2.2) indicated that the total methane emissions that can be reduced by the potential scenario amounted to approximately 200,000 tonnes while under the mitigation scenario the reduced emissions amounted to approximately 40,000 tonnes. The cumulative incremental benefits of both scenarios were approximately 111,118 US$ and 21,307 US$, respectively (Table 2.7). As the incremental benefit of implementing the options was significant, further analysis to identify and remove barriers for their implementation needs to be carried out. The increase in benefit is primarily due to the increase in rice productivity. Total rice production would increase by approximately 260,622 and 165,843 tonnes per season under the mitigation and potential scenarios, respectively (Table 2.7 and 2.8).

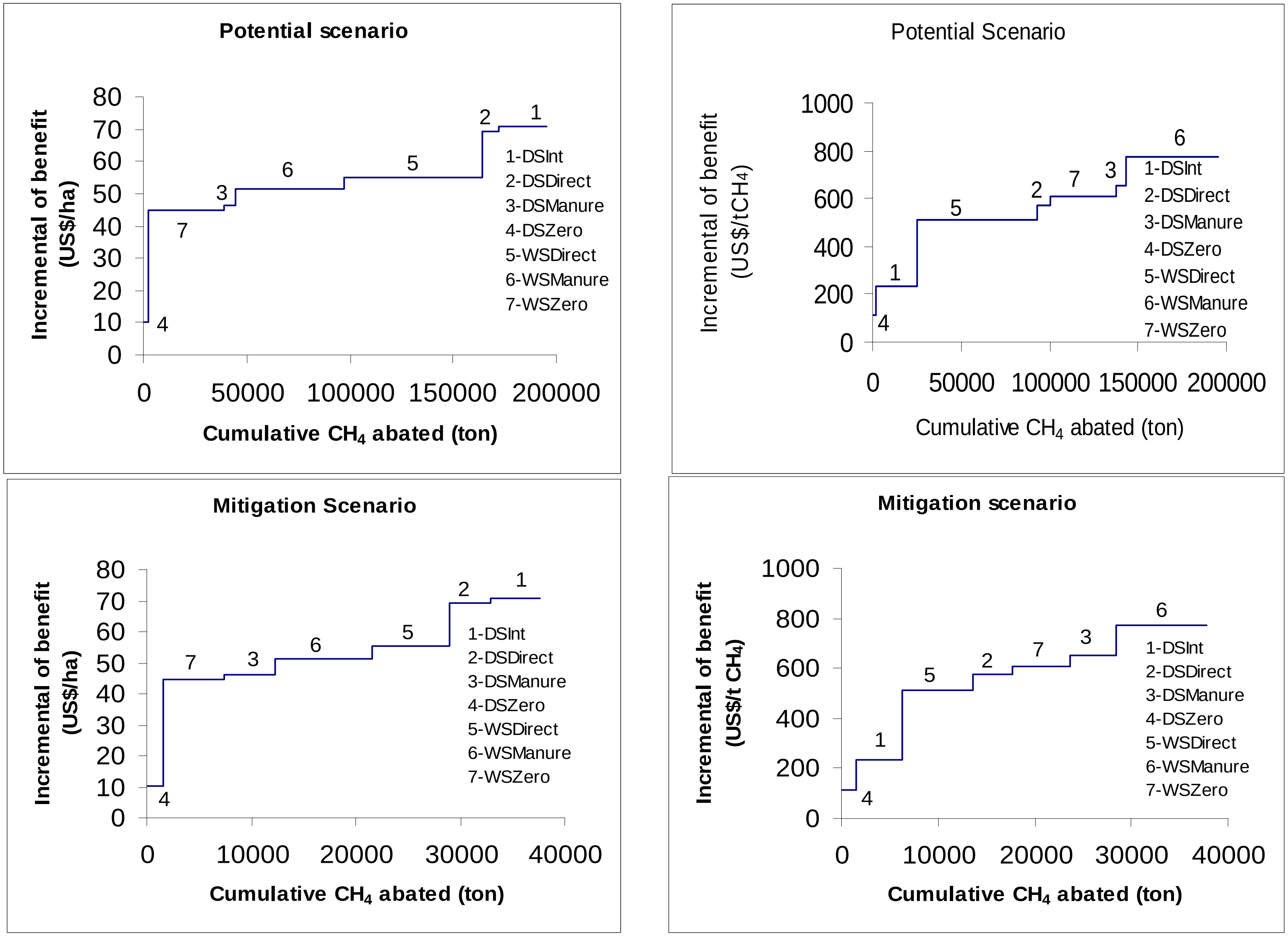

Figure 2.2: Carbon Emissions Reduction Initiative (CERI) for Both Potential and Mitigation Scenarios

Table 2.7: Cumulative Incremental Benefits under Mitigation and Potential Scenarios

Options	Cumulative Incremental Benefits (US$)	
	Potential Scenario	Mitigation Scenario
DSInt	5,398	1,108
DSDirect	9,836	3,401
DSManure	13,412	6,535
DSZero	13,657	6,711
WSDirect	48,278	10,514
WSManure	88,564	17,698
WSZero	111,118	21,307

Table 2.8: Estimated Incremental Rice Production under Potential and Mitigation Scenarios

Options	Incremental rice production (ton/season)	
	Potential Scenario	Mitigation scenario
DSInt	59,143	12,451
DSDirect	52,973	27,314
DSManure	44,246	39,074
DSZero	5,846	4,385
WSDirect	492,822	54,234
WSManure	538,110	95,847
WSZero	267,596	42,560
TOTAL	**1,460,736**	**275,865**

2.5. Conclusion and Recommendations

Seven options have been evaluated in this study, intermittent irrigation applied in dry season rice, organic matter management, direct seeded and zero tillage in both dry and wet season rice. All the options gave positive benefits with organic matter management considered as the option with the most potential, followed by intermittent irrigation, direct seeded and zero tillage. Organic matter management and direct seeded are already common practice in some provinces. Therefore, there may not be significant barriers with extending these options to other provinces. However, further research is required to evaluate the performance of the options in the country as most of the data used in this study were based on Indonesian data.

For the purpose of reducing methane emissions from agriculture sector by approximately 10% of the 1994 total emissions (approximately 40,000 tonnes of CH_4), the area that should be allocated for implementing the seven options is approximately 424,000 hectares. By implementing these options it is also expected that rice production would increase by approximately 275,865 tonnes. If all rice growing areas were used for implementing the seven options, the production would be expected to increase by approximately 1,460,736 tonnes.

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APPENDICES

Appendix 2.1: Cost and Other Input Data Used in the Analysis

(a) Rainfed Lowland Rice (wet season rice)

Per Hectare	**Inputs**		**Traditional System (Baseline)**		**Improved System (Mitigation)**	
	Unit	**U. Price**	**Quantity**	**Value**	**Quantity**	**Value**
I. Revenue						
Paddy1	Kg	368	1,300	478,400	2,000	736,000
Sub Total				478,400		736,000
II. Costs						
Seed1	Kg	368	80	29,440		
Improved Seed 2	Kg	800	0		80	64,000
Fertilizer	kg		0	0		98,800
Manure	Carts	0	5	0	10	0
Labor						
Family	Pers/day	0	110		120	
Hired	Pers/day	3,000			0	
Irrigation	/ha		0			
Hired Draft Power	/ha	95,650	1	95,650	1	95,650
Equip & Materials	/ha	25,800	1	25,800	1	25,800
Misc.	/ha		0			
Sub Total				150,890		284,250
III. Net Revenue				327,510		451,750
IV. Return/Pers-day				2,977		3,765

Source: Nesbett, H.J., and Helers, K. 1996. Rice in the Cambodian Economy: Past and Present, Rice Production in Cambodia, Cambodia-IRRI-Australia Project. Pp:20-21.

(b) Flood Recession Rice (dry season rice)

Per Hectare	Inputs		Traditional System (Baseline)		Improved System (Mitigation)	
	Unit	U. Price	Quantity	Value	Quantity	Value
I. Revenue						
Paddy1	Kg	368	2,700	993,600	3300	1,214,400
Sub Total				993,600		1,214,400
II. Costs						
Seed1	Kg	368	80	29,440		
Improved Seed2	Kg	800	0		80	64,000
Fertilizer				34,000		132,800
Manure	Carts	0	5	0	10	0
Insecticide (azodrine)	L	11,000	0		1	11,000
Labor						
Family	Pers/day	0	140		166	0
Hired	Pers/day	3,000	30	90,000	0	0
Irrigation	/ha	variable	1	66,000	1	116,000
Hired Draft Power	/ha	50,000	1	50,000	1	50,000
Equip & Materials	/ha	25,800	1	25,800	1	25,800
Misc.	/ha		0			
Sub Total				295,240		399,600
III. Net Revenue				698,360		814,800
IV. Return/Pers-day				4,108		4,908

Source: Nesbett, H.J., and Helers, K. 1996. Rice in the Cambodian Economy: Past and Present, Rice Production in Cambodia, Cambodia-IRRI-Australia Project. Pp.: 20-21.

Appendix 2.2: The Initial Cost for Wet and Dry Season in both Baseline and Mitigation Options (A&B)

A	Dry Season		Wet Season (Rainfed)		Dry Season	
	Baseline	**Mitigation**	**Baseline**	**Mitigation**	**Baseline**	**Mitigation**
Description of options	**Continuos flooding**	**Intermittent Irrigation**	**Nursery**	**Direct Seeded**	**Nursery**	**Direct Seeded**
Days trans-harvesting (day)	110	110	165	161	*110*	*106*
Emissions factor (kg/ha/day)	4.85	2.09	3.01	2.42	*4.85*	*3.9*
Total Emissions (kg/ha)	**533.5**	**229.9**	**497**	**389**	**533.5**	**412.8223**
Total Cost (Riel/ha)	**295,240**	**417,600**	**150,890**	**312,250**	**295,240**	**439,600**
Establishment cost (Riel/ha)	***50,000***	***50,000***	***95,650***	***83,650***	***50,000***	***50,000***
Land Rent	0	0	0	0	0	0
Seedling establishment cost	0	0	0	0	0	0
Land preparation cost	50,000	50,000	95,650	83,650	50,000	50,000
Land leveling cost	0	0	0	0	0	0
Transplanting cost	0	0	0	0	0	0
Establishing water control cost	0	*0*	0	*0*	0	*0*
Other cost-1	0	0	0	0	0	0
Other cost-2	0	0	0	0	0	0
Variable Costs (Riel/ha)	***245,240***	***367,600***	***55,240***	***228,600***	***245,240***	***389,600***
Irrigation management	66,000	***134,000***	0	*0*	66,000	116,000
Fertilizing			0	0		
Weeding	0	*0*	0	*0*	0	*0*
Crop protection	0	0	0	0	0	0
Harvesting	90,000	0	0	0	90,000	0
Seeds	29,440	64,000	29,440	**104,000**	29,440	104,000
Herbicides	0	0	0	0	0	0
Pesticide	0	11,000	0	0	0	11,000
Fertilizers	34,000	132,800	0	98,800	34,000	132,800
Other cost-1	25,800	25,800	25,800	25,800	25,800	25,800
Other cost-2	0	0	0	0	0	0
Other cost-3	0	0	0	0	0	0
Total Revenue (Riel/ha)	***993,600***	***1279,977.6***	***478,400***	***767,648***	***993,600***	***1,298,194***
Yield-1 (t/ha)	2.7	3.5	1.3	2.1	2.7	3.5
Price-1 (Riel/kg)	368	368	368	368	368	368
Yield-2 (t/ha) if exist	0	0	0	0	0	0
Price-2 (Riel/kg)	0	0	0	0	0	0
Profit (Riel/ha)	**698,360**	**862,377.6**	**327,510**	**455,398**	**698,360**	**858,593.6**

Appendix 2.2 (continued)

B	Dry Season		Wet Season (Rainfed)		Dry Season		Wet Season (Rainfed)	
	Baseline	Mitigation	Baseline	Mitigation	Baseline	Mitigation	Baseline	Mitigation
Description of options	**With Tillage**	**Zero Tillage**	**With Tillage**	**Zero Tillage**	**Without Manure**	**With manure Manure (2.5 t/ha)**	**Without Manure**	**With manure Manure (2.5 t/ha)**
Days trans-harvesting (day)	110	105	165	160	110	110	165	165
Emissions factor (kg/ha/day)	4.85	4.3	3.01	2.6	4.85	4.2	3.01	2.6
Total Emissions (kg/ha)	**533.5**	**447.1215**	**496.7069**	**422.8932**	**533.5**	**462.3667**	**496.7069**	**430.4793**
Total Cost (Riel/ha)	**295,240**	**349,600**	**150,890**	**188,600**	**295,240**	**399,600**	**150,890**	**284,250**
Establishment cost (Riel/ha)	***50,000***	***0***	***95,650***	***0***	***50,000***	***50,000***	***95,650***	***95,650***
Land Rent	0	0	0	0	0	0	0	0
Seedling establishment cost	0	0	0	0	0	0	0	0
Land preparation cost	50,000	0	95,650	0	50,000	50,000	95,650	95,650
Land leveling cost	0	0	0	0	0	0	0	0
Transplanting cost	0	0	0	0	0	0	0	0
Establishing water control cost	0	*0*	0	*0*	0	*0*	0	*0*
Other cost-1	0	0	0	0	0	0	0	0
Other cost-2	0	0	0	0	0	0	0	0
Variable Costs (Riel/ha)	***245,240***	***349,600***	***55,240***	***188,600***	***245,240***	***349,600***	***55,240***	***188,600***
Irrigation management	66,000	116,000	0	*0*	66,000	116,000	0	*0*
Fertilizing			0	0			0	0
Weeding	0	*0*	0	*0*	0	*0*	0	*0*
Crop protection	0	0	0	0	0	0	0	0
Harvesting	90,000	0	0	0	90,000	0	0	0
Seeds	29,440	64,000	29,440	64,000	29,440	64,000	29,440	64,000
Herbicides	0	0	0	0	0	0	0	0
Pesticide	0	11,000	0	0	0	11,000	0	0
Fertilizers	34,000	132,800	0	98,800	34,000	132,800	0	98,800
Other cost-1 (Manure)	0	**0**	0	**0**	0	**0**	0	**0**
Other cost-2	25,800	25,800	25,800	25,800	25,800	25,800	25,800	25,800
Other cost-3	0	0	0	0	0	0	0	0
Total Revenue (Riel/ha)	***993,600***	***1083,244.8***	***478,400***	***674,176***	***993,600***	***1,205,060***	***478,400***	***730,339.4***
Yield-1 (t/ha)	2.70	2.94	1.30	1.83	2.7	3.27	1.3	1.98
Price-1 (Riel/kg)	368	368	368	368	368	368	368	368
Yield-2 (t/ha) if exist	0	0	0	0	0	0	0	0
Price-2 (Riel/kg)	0	0	0	0	0	0	0	0
Profit (Riel/ha)	**698,360**	**733,644.8**	**327,510**	**485,576**	**698,360**	**805,460**	**327,510**	**446,089.4**