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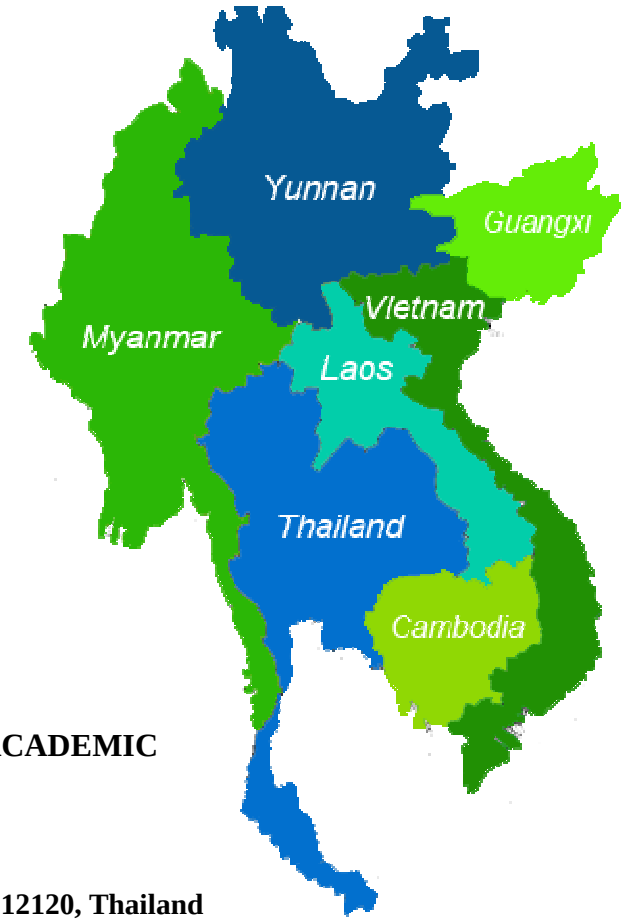

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GREATER MEKONG SUBREGION ACADEMIC AND RESEARCH NETWORK (http://www.gmsarn.com)

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The Greater Mekong Subregion Academic and Research Network (GMSARN) was founded followed an agreement among the founding GMS country institutions signed on 26 January 2001, based on resolutions reached at the Greater Mekong Subregional Development Workshop held in Bangkok, Thailand, on 10 - 11 November 1999. GMSARN was composed of eleven of the region's top-ranking academic and research institutions. GMSARN carries out activities in the following areas: human resources development, joint research, and dissemination of information and intellectual assets generated in the GMS. GMSARN seeks to ensure that the holistic intellectual knowledge and assets generated, developed and maintained are shared by organizations within the region. Primary emphasis is placed on complementary linkages between technological and socio-economic development issues. Currently, GMSARN is sponsored by Royal Thai Government.

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Greenhouse Gas Emission from Municipal Solid Waste in Phnom Penh, Cambodia

Chhay Hoklis and Alice Sharp

Abstract— *Municipal solid waste generation in Phnom Penh has steadily increased after the civil war in 1979. Currently, Cambodia, particular Phnom Penh, is focused on methods to reduce greenhouse gas emission from the waste sector. In the actual situation, all the municipal solid wastes are dumped into landfill without any gases captured for electricity generation. GHG emission in this paper was calculated based on the Intergovernmental Panel on Climate Change (IPCC) to estimate the GHG emission from municipal solid waste in Phnom Penh in 2009. The result of this calculation shows that the GHG emissions were 338.51 Gg (CO_2 eq) for CH_4, 3.26 Gg (CO_2 eq) for CO_2, and 6.43 Gg (CO_2 eq) for N_2O. Therefore, two waste management scenarios were proposed. In the two proposed scenarios, waste materials will be recycled by separation of waste at landfill, and composting of organic wastes at landfill as well. The result from these scenarios showed that greenhouse gas emission can be reduced by 5.95% for the first scenario and 27.98% for second scenario. This study revealed that the implementation of the proposed scenarios provides tremendous benefits. It can reduce the volume of waste entering landfill site, recycle waste materials, and minimize health problem.*

***Keywords*— Cambodia, Greenhouse Gas Emission, Intergovernmental Panel on Climate Change, Municipal Solid Waste Management, Phnom Penh.**

1. INTRODUCTION

Municipal solid waste (MSW) is a complex problem influenced by political, legal, educational, and economic factors. Growth in economic, population, urbanization, and industrialization has led to a large quantity of waste generation in developing countries, including Cambodia. Recently, the municipality of Phnom Penh has been faced with serious environmental and human health problems due to high population growth rate, poor waste treatment technology, and lack of skill of officers.

Up to now, Phnom Penh has only had one sanitary landfill for municipal solid waste, and the treatment technology is still very limited. Most of the methane from landfills and dumpsites is released directly to the atmosphere. It is clear that mismanagement of municipal waste management will result in greenhouse gas emission. Methane (CH_4), Carbon Dioxide (CO_2), and Nitrous Oxide (N_2O) are the main substances of greenhouse gases.

The aim of this study is to estimate the greenhouse gas emission in Phnom Penh by using the calculator developed by the Intergovernmental Panel on Climate Change (IPCC). GHG emission was calculated based on data collected in 2009. Additionally, two waste management scenarios were developed in order to find a way to reduce GHG emission as well as the volume of waste in landfill. Each scenario is focused on a composting method due to the large amount of organic waste produced in Phnom Penh, and agriculture sector. The factors analyzed in this study include waste generation, waste collection and transportation, waste disposal, and general problems of waste management in Phnom Penh, Cambodia.

2. CURRENT MUNICIPAL SOLID WASTE MANAGEMENT (MSWM) IN PHNOM PENH

Municipal solid waste management in Cambodia has improved slowly. Waste collection, transportation, and disposal site management are still limited due to lack of budget, and human resources. Therefore, Cambodia needs to develop a proper waste disposal system.

Waste generation

Waste generation in Phnom Penh increased rapidly from 338,647 tons in 2003 to 438,000 tons in 2009 (Table 1), and it was estimated to be 635,000 tons in 2015 (JICA, 2005). According to the Institute for Global Environmental Strategies (IGES, 2011), waste generation per capita in Phnom Penh was 0.91 kg/person/day. This rapid growth in waste generation was attributed to population growth and economic development. It should be noted that the solid waste collection in 2004 was 227,910 tons/year which was lower than that of 2003, at 240,859 tons/year. This was not because less waste was generated, but due to low collection efficiency and data management. The waste composition of Phnom Penh city is shown in Table 2. It is revealed that food waste is the main component of waste of the organic fraction with high moisture content. This organic fraction of waste plays important role on methane gas emission.

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Waste collection and transportation

Currently, there is only one private company that is responsible for municipal solid waste management as well as for cleaning services in Phnom Penh city. This company is called CINTRI (Cambodia) Co., Ltd. It is a private waste management firm. Bunrith, S., et al, (2010), reported that CINTRI started its service in 2002, and from 2009 waste collection and transportation service in Phnom Penh has been completely provided by CINTRI. The company now has a monopoly on waste services and a contract of fifty years. Hence, CINTRI definitely fills an important need in the city. However, CINTRI's monopoly means that there is no open market for waste services and no bidding between competitors working to get prices down.

Waste collection and transportation are very useful to enhance waste management. Recently, waste collection in Phnom Penh has improved due to the aim of the Ministry of Environment (MoE) to make the city clean. According to Table 1, almost 84 % of solid waste in this city was collected in 2009. For waste transportation, the city does not have a transfer station. All the collected waste is transported directly to a disposal site.

Waste disposal

Open dumpsites and landfills are the common methods being practiced in Cambodia as well as other developing countries, such as Thailand and Vietnam. The MSWM systems start with collecting, buying, and scavenging of recyclable materials from households and commercial sectors. In Phnom Penh, informal waste pickers collect recyclable materials and sell them to recycle shop. Then, these materials such as plastic, paper, cloths, and metal, are put through a simple process (pre-recycle process) before being sent abroad for further recycling processes. If domestic recycling can be done with standardized quality, it will create economic benefits for local citizens.

In the past, most of the remaining wastes were sent to Steung Mean Chey dumpsite located in Phnom Penh, Cambodia with a total area of 6.8 ha. This disposal site is an open dumping site without environmental protection measures. The site has poor planning, and a low level of technology employed. During the rainy season, the area is flooded, and the fetid water submerges the surrounding residential areas. Waste is often burnt in a field to reduce the volume of waste.

At present, waste disposal site has changed from Steung Mean Chey dumping site (SMCDS) to the Dong Kao site. Dong Kao landfill is the first sanitary landfill which was built in Phnom Penh at a total area of 26 ha (11 ha for disposal area) and it has been allowed to be used since 2009. It has a daily soil-covering process to reduce the bad odor and protect the environment. Furthermore, leachate storage ponds have been constructed. Yet, it has no leachate treatment. The leachate is just pumped into the pond and left to evaporate.

3. PROBLEMS RELATED TO CURRENT SITUATION

Municipal solid waste (MSW), produced in Phnom Penh is growing in volume and in toxicity. The MSW recently still is improperly managed. Problems related to solid waste management are summarized as follow:

- The classification of solid waste has not yet been implemented. Mixed solid wastes (industrial and domestic wastes) are disposed of at the same dump site. Moreover, there is no waste segregation for recycling before disposal in the landfill.
- In practice, the landfill does not have environmentally sound management. The knowledge on waste treatment technology and wastewater (leachate) is still limited. Landfill produces negative effects to dwellers that live around dump sites. They cause a risk to public health directly or indirectly, especially to scavengers that seek available things at dumping sites or people who live close to dump sites.
- For the collection service, ineffective solid waste collection and insufficient number of waste collection trucks are the reasons for piles of waste in public areas and market places.
- During rainfall, solid waste and garbage were washed out and clogged sewage systems in urban area, and finally flooded adjacent low-level residential areas.
- To conclude, all of these need new approaches in order to manage municipal solid waste properly and use appropriate technology that can be easily maintained and operated.

Table 1. Waste generation and collection in Phnom Penh

Year	2003[a]	2004[a]	2005[a]	2006[a]	2007[a]	2009[b]
Daily waste generated (Tons/day)	928	986	1,043	1,101	1,159	1,200
Annual waste generated (Tons/year)	338,647	359,717	380,786	401,856	422,926	438,000
Solid waste collected (Tons/year)	240,859	227,910	266,781	324,159	343,657	366,825
Solid waste uncollected (Tons/year)	97,788	131,807	114,005	77,697	79,269	71,175
Uncollected (%)	29	37	30	19	19	16.25

[a] Phong, H., (2010)
[b] IGES 2011

4. GHG EMISSION FROM WASTE SECTOR

Municipal solid waste that is produced by human activities contributes significantly to greenhouse gas (GHG) emissions. Greenhouse gas from the waste sector has an effect on climate change that creates global problems. The GHGs that are making the largest contribution to global warming are CO_2, CH_4, and N_2O. According to Pikoń and Gaska, (2010), one ton of CH_4 emissions have the same potential effect on global climate change as 21 tons of CO_2. Thus, one ton of CH_4 emissions can be expressed as 21 tons of CO_2 eq. And one ton of N_2O has the same potential effect on global climate change as 310 tons of CO_2.

All three gases are produced during waste management and waste disposal. Emission of methane gas happens when organic waste is left to decay in anaerobic landfills.

5. GREENHOUSE GAS ESTIMATION FROM THE WASTE SECTOR

The IPCC calculator is a simple tool for GHG emission estimation that requires only input of a limited set of parameters. This method assumes that all the potential GHG emissions are released during the same year that waste is disposed of without consideration of the timing of the emissions. According to Chiemchaisri and Chettiyappan, (2008), IPCC is estimated based on the category of the waste, degradable organic carbon (OC) fraction, and methane (CH_4) gas in landfill. CO_2 and N_2O were also determined, but CH_4 is the main gas in GHG emission, following equation (1). For the estimation of GHG emission for this study, the fraction of DOC is equal to 0.1508. It is assumed that the fraction of methane in landfill gas equal 0.5. And the oxidation factor (OX) was assumed to be zero because oxidation of carbon dioxide was not taken in account. There was no recovery or generated methane gas. Thus, R was equal to zero.

Table 2. Typical composition of MSW in Phnom Penh

Year / Composition (%)	2002[a]	2003[a]	2009[b]
Food/Organic	65	63.3	70
Plastic	13.2	15.5	6
Paper & Cardboard	3.8	6.4	5
Grass & Wood	-	6.8	6
Glass	4.9	1.2	2
Metal	1	0.6	2
Rubber, Leather	0.6	0.1	-
Textile	-	2.5	3
Ceramic & stone	-	1.5	-
Other	11.5	2.1	6

[a] Bunrith, S et al., 2010
[b] IGES, 2011

$$CH_4 \text{ emissions} = (MSW_T \times MSW_F \times MCF \times DOC \times DOC_F \times F \times 16/12\text{-}R) \times (1\text{-}OX), \quad (1)$$

where

MSW_T : Total MSW generated (Gg/yr)
MSW_F : Fraction of MSW disposed of in solid waste disposal sites
MCF : Methane correction factor (fraction)
DOC : Degradable organic carbon (fraction) (kg C/kg SW)
DOC_F : Fraction DOC dissimilated
F : Fraction of CH_4 in landfill gas (IPCC default is 0.5)
16/12 : Conversion of C to CH_4
R : Recovered CH_4 (Gg/yr)
OX : Oxidation factor (fraction – IPCC default is 0)

6. SCENARIO DESCRIPTIONS

Two scenarios are proposed to develop municipal solid waste management in Phnom Penh. GHG emission estimation from each scenario and actual situation of waste management are summarized in Table 3.

Actual situation- 100% of waste is disposed of in landfill

Solid wastes are mainly disposed of in landfill, because landfill is the simplest, cheapest and most cost-effective method of disposing waste. For developing countries, almost 100% of generated waste goes to landfill. Even in many developed countries, most solid waste is landfilled. Based on current municipal solid waste management in Phnom Penh, it is assumed that 15% of total waste generation is released to open dumping sites. It is considered as uncollected waste due to road conditions and improper management. About 15% of waste generation was sent to landfill, Steung Mean Chey dumping site. Furthermore, almost 10% of total waste generation that is released to SMC site is considered for open burning, for the actual situation in 2009, Phnom Penh. The remains 5% of waste is assumed to be recycled by scavengers. About 9% of waste material is recycled as composting by some NGOs, such as Cambodian Education and Waste Management (COMPED) and Community Sanitation and Recycling Organization (CSARO). In this scenario, 100% of solid waste is released directly to landfill without separation of the waste material for recycling or gas collection. It is good if gases can be captured from landfills and converted to electricity for supplying the country.

For the other two scenarios, managed landfill and composting were considered to improve waste management and reduce GHG emission. There is no methane collection or recovered energy gas from landfill sites. Moreover, it is assumed that there is no open burning of waste at Dang Kao landfill. The aim to develop these scenarios is that the composting method should be promoted, based on the large amount of organic waste produced in Cambodia, in order to improve the agricultural sector as well as reduce the amount of waste in landfill sites. In addition, reducing waste at landfills is very important to practice in Phnom

Penh, in order to recycle waste material.

Scenario 1- Reduction of waste at landfill + 20% of organic waste for composting + landfill

Landfills have negative effects on the environment such as GHG emissions and leachate. So, many countries including Cambodia have concerns over landfill issues, such as an increasing of groundwater contamination, potential release of toxic gases, and odour. A big part of these problems comes from organic waste. That is why this scenario is applied to mix the management practice of compost to minimize these problems.

Waste reduction at landfill is very important in this scenario to remove some materials such as plastic, paper, and metal from the landfill. Recycling of these materials is useful for proper waste disposal. This can reduce energy consumption and pollution, conserve natural resources, and extend valuable landfill space. This can also have economic benefits by reducing costs associated with operation at disposal.

Therefore, it is assumed that 70% of paper, plastic, and metals are removed for recycling, and 20% of organic waste is removed for composting. Furthermore, waste material needs to be separated for recycling before release to the landfill. The remaining wastes from recycling and composting are sent to landfill without gas recovery.

Scenario 2- Reduction of waste at landfill + 50% of organic waste for composting + landfill

In this scenario, there is also waste reduction at landfill by removing recyclable materials: plastic, paper, and metal. It is assumed that 70% of recyclable materials, such as paper, plastic and metal are removed with 50% of organic waste diverted for composting. The remaining solid waste is released to the landfill. This is quite the same as scenario 1, but it uses composting as much as possible to reduce GHG emission as well as the amount of waste in landfill.

7. RESULT

This study shows that greenhouse gas estimated for the actual situation by the IPCC calculator is 338.51 Gg (CO_2 eq) for CH_4, 3.26 Gg (CO_2 eq) for CO_2, and 6.43 Gg (CO_2 eq) for N_2O in 2009. Waste management should be improved in order to reduce environmental problems as well as reduce GHG emissions. Therefore, two developed scenarios (scenario 1 and 2) were introduced to reduce the greenhouse gas emission from Phnom Penh waste dumpsite. The first scenario is that 20% of organic waste is removed for composting. In the second scenario, 50% of organic waste is removed for composting. In both new scenarios, it is assumed that there are composting and waste reductions at landfill by the removal of recyclable material: plastic, paper, and metal.

Table 4 shows the greenhouse gas emission in Phnom Penh for the actual situation and two developed scenarios. It is revealed that GHG emission can be reduced, if 70% of waste materials, such as paper, plastic and metal are removed, with 20% of organic waste for composting. GHG emission is more reduced in the case that 50% of organic waste is removed for composting. The estimated GHGs of scenario 1 is 320.64 Gg (CO_2 eq) for CH_4 and 6.84 Gg (CO_2 eq) for N_2O. IPCC calculated 233.67 Gg (CO_2 eq) for CH_4 and 17.11 Gg (CO_2 eq) for N_2O for scenario 2. It should be noticed that there is no CO_2 emission for these two developed scenarios because it is assumed that there is no open burning in landfill.

These results revealed that greenhouse gas emission reduced 5.95% for the first scenario and 27.98% for the second scenario. This is due to promoting the composting method, and reducing waste at landfill for recycling paper, plastic and metal.

Table 3. GHG emission in Phnom Penh

GHG emission Gg (CO_2 eq)/year	Actual situation	20% compost	50% compost
CH_4	321.71	304.26	222.33
CO_2	3.26	-	-
N_2O	6.43	6.84	17.11
Total	331.40	311.10	239.44
GHG reduction (%)		3.26	27.75

8. RECOMMENDATION TO IMPROVE PROBLEMS

In MSW management practices, not only the end of pipe approach, but also a precautionary approach should be considered, such as waste prevention or waste reduction at source, in order to minimize waste in the final disposal (landfill). Moreover, this prevents emissions of many greenhouse gases, reduces pollutants, saves energy, conserves resources, and reduces the need for new landfills. Waste prevention should be promoted to reduce the amount of waste generation:

- Plan meals to avoid waste generation;
- Bring own shopping bag and use only big ones at the grocery store;
- Buy goods from local farmers' markets;
- Buy, maintain, and repair products;
- Use pink-lotus leaf instead of paper or plastic to wrap things;
- Buy only what you need.

Moreover, there are several recommendations for future improvement of solid waste management in Cambodia, especially Phnom Penh, capital city of the Kingdom of Cambodia.

- Improving public information on municipal solid waste management and waste disposal and treatment. In this case, MoE has to play in important role in collaboration with other ministries like the Ministry of Education or NGOs.
- Improving transportation and solid waste collection service: The transportation and collection

service are still weak. That is why they should consider the schedule of collection.

- Installing a sanitary landfill that has technology for treatment of waste materials: In this case, Cambodia will also gain the benefits from solid waste by collecting methane gas from landfills to be converted into electricity, which can be supplied to the country. Cambodia imports electricity from neighboring countries. Government should encourage investors like NGOs or private companies to invest in solid waste in Cambodia. In addition, the government should improve and encourage private companies or NGOs to do the composting because it can reduce the amount of organic waste. Moreover, Cambodia is an agricultural country; most farmers need compost to supply their plants.

In short, all of these need to be supported and implemented by adequate funds for technology and skilled human resources. Officials at the subnational level should be better trained in integrated solid waste management, while funds are needed for waste collection equipment and the development of MSW management. Furthermore, public awareness of MSW management issues could also be improved. Therefore, an integrated solid waste management plan should be developed; each component should be more clearly delegated to the responsible authorities. Moreover, funds should be mobilized towards implementation despite a limited national budget.

9. CONCLUSION

The calculation has shown that good waste management is the basis for reducing GHG emission and minimizing pollutants.

Since Cambodia is a developing country in Asia, the main component of the solid waste generated is organic waste. Composting can be improved and promoted for the agricultural sector. Sanitary landfill should be applied for this country due to population growth as well as increasing waste generated. Although, incineration seems to be the best method of waste management to not only protect the environment, but also get a lot of benefits. However, Cambodia does not have enough funds and skill of human resources to apply these methods. Therefore, to reduce the amount of solid waste, the government should initiate more 3R activities in solid waste management policies. The advantage is that the informal sector recycles a portion of the country's urban waste. Finally, the need to reform the solid waste management strategies is an opportunity not just to turn municipal waste into a valuable resource, but also to increase the income of the informal waste pickers, reduce poverty, and contribute towards the mitigation of climate change, by reducing GHGs emissions. Therefore, the government should consider improving the waste management system and the economic conditions of Cambodia.

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