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Estimating Methane Gas Emissions from Solid Waste Generated by Households in an Urban Village in Bukidnon, Philippines

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Abstract: To provide inputs to solid waste management planning with a climate change perspective for an urban village in Bukidnon, Philippines, a waste analysis and characterization study (WACS) was conducted in Barangay Dologon, Maramag Town in Bukidnon, Philippines. Methane emissions from landfills based on waste generation data were then estimated. From this, future waste management scenarios with different waste diversion rate targets were tested in terms of methane emissions avoided. Descriptive statistics (mean and percentage) were used in the data analysis. Furthermore, non-parametric inferential statistics (Friedman test and Nemenyi test) were used to compare the different waste management scenarios in terms of its equivalent methane emissions. The study found out that food waste is the main contributor of methane emissions in the village which means a great potential for methane reduction through composting. Paper waste provides only a minimal methane emission reduction due to the small amount of this type of waste from the village. A minimal 25% waste diversion rate in food, yard and mixed paper waste is enough to significantly decrease methane emission from waste in the village. The study recommends streamlining of climate change mitigation in solid waste management planning in the village.

Key words: Solid waste management · Climate change · Methane emissions · Bukidnon · Philippines

INTRODUCTION

Though it is always understood that proper waste management helps protect the health and well-being of citizens, many failed to realize that solid waste also impacts climate change. The processes involved in the manufacture of products up to its disposal as waste all result in emissions of atmospheric gases called “greenhouse gases” that leads to global warming and climate change. When organic waste decomposes in landfills and uncontrolled dumps, it produces methane, one of the major greenhouse gases contributing to climate change [1]. Methane is second to carbon dioxide in being the largest contributor to global warming among anthropogenic greenhouse gases. The global warming potential of methane (over a 100 year time horizon) is 21 times greater than that of carbon dioxide [2].

Open dumping and improper landfilling of municipal solid waste (MSW) is reported to contribute to 3–19% of the anthropogenic sources of methane emissions globally. Thus, reduction of methane emissions from landfill sites would greatly reduce greenhouse gases in the atmosphere [3].

Methane comprises more than 55% of the atmospheric concentration of all emissions from landfill sites. Furthermore, carbon dioxide comprises more than 37% of these emissions [4]. In the Philippines, the Manila Observatory has recorded 6,357 kilotons of carbon dioxide emissions from solid waste in Philippine urban populations in 1994. Aside from that 302.73 kilotons of methane are produced from solid waste in the same year [5]. In a study conducted in Taiwan, the average methane emission rate is estimated to be 13.17, 65.27 and 0.99 $mg/m^2/hr$ as measured by gas chromatography chamber method in 1–2, 2–3 and 5 year-old landfill, respectively [6].

The alarming rate of methane production in our landfills where most of our household wastes end up, motivated the researchers to look into this matter—addressing climate change through solid waste management at the community level. A waste analysis and

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characterization study was undergone to estimate the waste generated by an urban village. Furthermore, methane emissions which result from the dumping of biodegradables (which produces methane when decomposed) were estimated using the waste generation data. Future waste management scenarios were then tested in terms of its ability to reduce methane emissions.

MATERIALS AND METHODS

Sampling and Data Gathering: Primary data on household waste generation was obtained through a Waste Analysis and Characterization Study (WACS) based on methods specified by the Philippine EcoGov (Environmental Governance) Project [7]. Thirty households were chosen as the sample of the study. This specific sample size is the minimum specified by EcoGov which can represent a small geographical unit in gathering waste generation data. Similar waste analysis and characterization studies utilized a range of 30-60 households as sample sizes [8-10].

The thirty households were purposively chosen and stratified among the different *Puroks* (Subvillages) in Barangay Dologon (Barangay is the smallest geographical unit in the Philippines equivalent to a village in most countries). The village is located in Maramag Town, in Bukidnon, an agricultural province in the Philippines. Purely residential households were chosen for the sampling, thus households with businesses (e.g. stores, shops, etc.) were excluded. Plastic garbage bags were provided to the sample households to serve as containers of their daily household wastes. Wastes in the bags were collected daily for eight consecutive days. The first day of the study is not officially considered as part of the analysis but instead serve as a "practice day" for data gathering. Furthermore, collection on the first day is meant to get rid of the accumulated wastes in the household prior to the actual date of study. Hence, actual data came from the official seven days (1 week) of data collection after the "practice day".

Total wastes from each household were weighed daily then segregated in terms of the different major waste categories: food waste (kitchen waste, fruit and vegetable peeling, etc.), yard waste (twigs, leaves, etc.), paper, glass bottles, plastic bottles, tin cans, cellophanes, etc. Each waste category was then weighed separately per household.

Per capita waste is computed by dividing the total daily waste per household by the number of family members. Daily waste is calculated by dividing the weekly waste by the number of days of data gathering (7 days).

The actual data gathering was done on January 17 to 24, 2013. Based upon the EcoGov specification, the study was conducted on a normal week in the community (e.g. no festivals, no family celebrations, etc.) to avoid biases due to abnormal waste generation from non-normal activities of the family.

Estimating Annual Methane Emissions from Wastes: Estimation of methane emission from wastes is based on the U.S. Environmental Protection Agency [11] methane emission factors for wastes disposed in landfills. These factors were multiplied with the annual waste generation of the village specifically of the following biodegradable wastes: food, yard and mixed paper. Daily per capita waste of each mentioned type of waste is multiplied with the population in the village at the time of the study (N = 12,318) then multiplied by the number of days in a year (365) to estimate the annual waste generated by the whole village population.

Developing Waste Management Scenarios: To analyze the effect of different village level waste management activities on the methane emissions from waste, three scenarios were developed namely: 0% diversion rate (status quo or no intervention), 25% diversion rate (minimal intervention) and 60% diversion rate (maximum intervention based on national target by 2016 [12]). The effect of the implementation of the mentioned waste scenarios on methane emissions were analyzed through descriptive comparison using percentage of methane emissions avoided if diversion rate is realized.

Data Analysis: Descriptive statistics (average and percent) were employed in analyzing the data gathered in the study. Furthermore, Friedman test was utilized in comparing the waste management scenarios in terms of methane emissions. Post hoc analysis using the Nemenyi test was also done.

RESULTS AND DISCUSSION

Waste Generated by Residents of the Study Area: Table 1 shows the amount of waste in kilograms per capita daily (kg/capita/day) generated by residents of the study area. It is observed that the average daily per capita waste generated by the residents is 0.366 kg/capita/day. This is close to the average daily per capita estimate in rural areas in the country which is 0.3 kg/capita/day. The average Filipino is estimated to produce around 0.3 to 0.7 kg/capita/day of solid waste [13]. This means that the average resident in the village is comparable to an

Table 1: Weight of solid waste generated in the study area by category.

Type of Waste	Weight in kg/capita/day	Percentage (%)
Food waste	0.113	30.87
Yard waste	0.143	39.07
Mixed paper	0.013	3.55
Glass bottles	0.003	0.82
Plastic bottles	0.006	1.64
Tin cans	0.006	1.64
Plastic cellophane	0.042	11.48
Dirty plastic bags	0.027	7.38
Sanitary napkins/diapers/dirty cotton etc.	0.013	3.55
Total	0.366	100.00

average Filipino in terms of waste generation. Furthermore, on a global scale, this means that an average resident of the village generates almost the same amount of waste as an average resident of Nepal (0.3 kg/capita/day) and slightly lower than an average citizen of India (0.47 kg/capita/day) and Bangladesh (0.50 kg/capita/day) [14].

Based on the type of waste generated, the largest amount of waste by weight is yard waste (~39%) followed by food waste (~31%). The types of waste with the lowest amount by weight are plastic bottles (1.64%), tin cans (1.64%) and glass bottles (0.82%).

Generally, most of the waste produced by residents of the village is biodegradable wastes (food waste and yard waste). These comprise ~70% of the total waste generated by the residents. Recyclables (mixed paper, glass bottles, plastic bottles, tin cans and plastic cellophane) comprise ~19% of the total waste generated by the residents. The rest (~11%) are residual wastes (wastes which cannot be recycled or composted) such as dirty plastic bags, sanitary napkins, disposable diapers, etc.

On a global perspective, developing countries have the highest proportion of organic waste. Consequently, plastics and other inorganic materials make up the highest proportion of solid waste in developed countries [15]. In the context of Asia, low and middle income countries have a high percentage of compostable organic matter in the urban waste stream, ranging from 40 to 85 percent of the total in 1999 [16]. Presently, the average percentages of organic matter in the solid waste in major cities in Asian countries ranged from 50% to 70% [14]. This validates the waste generation data produced in the study.

In comparison to Metro Manila, the Philippine capital, there is a higher percentage of biodegradable waste in the study area than the national capital which has 49% of the said type of waste generated. However, Metro Manila has a higher percentage of recyclable wastes with 42%. Furthermore, the study area has a higher percentage of residual wastes generated than the national capital [13].

The above results reflect the greater potential of the village for reduction of waste through composting as evidenced by the majority of wastes being biodegradable hence compostable. To a certain extent recycling can also be a good option for waste reduction as around 1/5 of the total waste produced is recyclables. Thus, an optimal waste scenario (100% composting and recycling) would result to only ~11% of waste ending up in landfills based on the amount of residuals observed in the study.

Methane Emissions from Annual Biodegradable Waste Generated: Because non-biodegradable wastes are considered inert materials in landfills (materials which do not decompose or cannot be naturally degraded), the conversion of waste into its equivalent methane emission refers only to biodegradable. In this particular context food waste, yard waste and mixed paper are the only waste types considered to decompose naturally. Based on population data as well as methane emission factors of wastes, annual methane emissions in metric tons of carbon equivalent (MTCE) were computed.

As shown in Table 2, the total amount of annual methane emissions is equivalent to 3,907.26 metric tons carbon equivalent (MTCE). This is equivalent to 14,327 metric tons of carbon dioxide equivalent (tCO_2e) or roughly around 1,612,087 gallons of gasoline consumed. Consequently, this needs approximately 15,081.05 hectares of an average forest to sequester the said amount of carbon in a year.

The largest annual methane emissions from biodegradable waste generated in the area comes from food waste (2,032.22 MTCE) followed by yard waste (1,530.19 MTCE). The large amount of methane emissions from yard waste is attributed to its larger methane emission factor rather than the amount of generation of this type of waste in comparison to yard waste.

Furthermore, mixed paper waste in the area has the lowest equivalent methane emissions (344.85 MTCE) among all the types of biodegradable waste generated in

Table 2: Estimated methane emission from biodegradable waste in the study area.

Type of Biodegradable Waste	Estimated Annual Waste	Emission Factor in MTCE/ton	Annual GHG Emissions in MTCE
Food waste	5,080.56	0.400	2,032.22
Yard waste	6,429.38	0.238	1,530.19
Mixed paper	584.49	0.590	344.85
Total	12,094.43		3,907.26

Table 3: Annual methane emissions reduction based on different waste management scenarios.

Waste Management Scenario	CH_4 Emissions Avoided from Food Waste (MTCE) *(% Reduction of Total Methane Emissions)*	CH_4 Emissions Avoided from Yard Waste (MTCE) *(% Reduction of Total Methane Emissions)*	CH_4 Emissions Avoided from Mixed Paper (MTCE) *(% Reduction of Total Methane Emissions)*
0% Diversion Rate	0.00 *(0%)*	0.00 *(0%)*	0.00 *(0%)*
25% Diversion Rate	508.05 *(13%)*	382.55 *(10%)*	86.21 *(2%)*
60% Diversion Rate	1,219.33 *(31%)*	918.11 *(24%)*	206.91 *(5%)*

Table 4: Statistical comparison between the different waste management scenarios in terms of annual methane emissions

Waste Management Scenarios	Total CH_4 Emissions (MTCE)	Mean Rank	X^2 (df = 2)	p-value	Significant Differences
0% Diversion Rate	3,907.26	3	6.000	0.050	0% & 25%*
25% Diversion Rate	2,930.45	2			25% & 60% *
60% Diversion Rate	1,562.91	1			0% & 60%**

* Significant at 0.10, **Significant at 0.050

the village. In this case the low amount of equivalent methane emission is due to the low generation of such waste in the area rather than its methane emission factor.

Methane Emissions Reduction under Different Waste Scenarios: As shown in Table 3, the largest reduction in methane emissions comes from a 60% diversion in food waste (31% methane reduction) which is even greater than the combined methane emissions reduction from a 60% diversion in both yard waste and mixed paper waste. Even at minimal 25% diversion in food waste will result to a 13% methane emissions reduction which is more than half of the methane reductions from a 60% diversion of yard waste. Consequently, even the combined 25% diversion of both yard waste and mixed paper waste is still a bit lower than methane emissions reduction from a 25% diversion of food waste. Mixed paper waste reduction has the lowest methane emissions reductions in both waste management scenarios. In fact, a 100% diversion in mixed paper waste is equivalent to only 8% of total reduction in annual methane emissions from biodegradable waste generated by the villagers.

The above results can be attributed to the large methane emission factor from food waste compared to yard waste. Thus, even if yard waste is the larger amount of waste produced by the village compared to food waste, higher methane emissions would still come from food waste generated by households in the area because decomposition of food waste produces more methane than the decomposition of yard waste. Furthermore, mixed paper has the largest emission factor among the biodegradable wastes generated in the study area; however, the village only generates a minimal amount of this type of waste. Mixed paper thus has the lowest potential for methane emission reduction in the area. On the other hand, food waste reduction provides the greatest potential for methane emissions reduction in the village followed by yard waste reduction.

Statistical Comparison of Annual Methane Emissions from Different Waste Management Scenarios: As shown in Table 4, a Friedman test was conducted to determine if there are significant differences in the annual methane emissions from waste generated among the different waste management scenarios. There is a statistically significant difference in methane emissions depending on the waste management scenario being implemented, $X^2 = 6.000$, p = 0.050. Post hoc analysis using Nemenyi test was done to determine significant differences among the different pairs of waste management scenarios. The maximum intervention (60% diversion rate) scenario is significantly different from the no intervention (0% diversion rate) scenario at 95% confidence level in terms of methane emissions. On the other hand, minimum intervention (25% diversion rate) scenario is significantly different from both the no intervention and maximum intervention scenarios in terms of methane emissions at 90% level of confidence.

The above results mean that even a minimal 25% diversion rate can significantly reduce methane emissions from waste at 90% confidence level. Furthermore, a 60% diversion rate leads to a significant reduction in methane emissions from household wastes at 95% level of confidence.

CONCLUSIONS

The average daily waste generated by residents of Barangay Dologon is 0.366 kg/capita/day. This is within the average national range but lower than the average of other countries in Asia. Yard waste comprises the majority of waste produced by the residents of the area. Food waste on the other hand, is the main contributor of methane emissions from wastes of residents in the area. Mixed paper waste generated by residents in the area is shown to have the lowest contribution of methane emissions.

In terms of reduction potential it is revealed that diversion of food waste has the largest potential for methane emission reduction. In fact, based on a nationally mandated waste diversion scenario (60%) for food waste alone leads to a 1/3 decrease in the total annual methane emissions. On the other hand, diversion of waste paper only provides minimal methane emission reduction. Even a 100% diversion in mixed paper waste only leads to ~8% reduction from of methane emissions. Furthermore, even a minimal 25% diversion rate in overall generated waste significantly reduces methane emissions from biodegradable waste in the study area compared to a status quo (no intervention) scenario.

The information above will provide assistance for community leaders in providing inputs for future waste management strategies. Furthermore, the study results can initiate dialogues related towards the streamlining of climate change mitigation in solid waste management planning especially at the community level.

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