Environmental Impacts of Methane Fermentation System Using Hot Springs

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Abstract

For establishing one of effective biomass-using system on hilly and mountainous regions in Japan, we developed the small methane fermentation system for garbage using hot spring. This study evaluated the environmental impacts and cost in the system. We used life cycle assessment methods using the actual data from our system and the inventory data. Energy consumption and global greenhouse gas emissions were used as the indicators of environmental impacts. In these results, the environmental impacts of initial material inputs (67.9 GJ, 4.96 t CO_2) were much larger than ones of operations (2.24 GJ / year, 0.361 t CO_2 / year). The balances between the environmental impacts of the initial and operations and the alternative effects such as methane utilization, slurry utilization, using garbage treatment and using hot spring were minus except for the balance between only inputs and methane utilization. It is suggested that our proposed system has the reduction effect of environmental impacts. In comparison with the centralized large-scale methane fermentation system, the cost of our system was cheaper than the centralized system. Assuming the introduction of our system to Naruko area, located on hilly and mountainous regions in northern part of Japan, the total cost of our system was half of the centralized system. The balances of energy consumptions and global greenhouse gas emissions were -347 GJ and -2.50 t CO_2 per year in our system and 216 GJ and 41.1 t CO_2 per year in the centralized system. This proposed system should be the key technique of the reduction of environmental impacts using bioenergy in hilly and mountainous regions.

Introduction

The various bioenergy production systems, which are expected to contribute to Japan's energy security and induce a lower climate change potential, have recently been receiving high attention (Gnansounou et al. 2009). Especially in organic waste from livestock and human, the methane fermentation system was expected because organic wastes generally have the high water contents and are unsuited for use in burning. On-farm methane fermentation system has been wide-spreading for livestock waste treatment in Japan (e.g. Hishinuma et al. 2002, 2008, Ishikawa et al. 2006) as well as Europe (Collet et al. 2011). On the other hand, the centralized methane fermentation system, which typically has larger-scale than on-farm system, could be suitable for human waste but the system has been underused (reviewed in Nakamura 2011). If the well-developed transportation network, the large population and the wide space enough to built a plants exist in the system-produced area, the centralized large-scale methane fermentation system may have economical and environmental benefits: but, even in this case, the problem of slurry treatment from the system may be remained (Nakamura 2011). It is difficult to build such a large-scale methane fermentation plant in hilly and mountainous regions, which occupy about 70 % of total land area in Japan. In such regions, there are a lot of resort areas in Japan. In these areas, three times garbage per capita is producedbecause many dishes are served based on Japanese traditional hospitality in accommodations (personal communication with Naruko Machi-zukuri, a community facilitation company in Naruko area). The effective treatment and usage of the garbage in such an area are urgently needed in Japan.

We are thinking one of potential energy source in the resort areas is hot spring that Japanese most resort areas have. Most hot springs have been used for only bathing activity but have a numerous thermal energy. Recently, some communities in the resort areas have been using this energy (Okumura et al. 2010). In the case using hot springs as energy, most are directly used as a thermal energy, e.g. central heating. as well as Iceland. We considered to use this thermal energy for methane fermentation. The thermal energy of hot springs is more suitable than energy from fossil fuel because the thermal energy for methane fermentation is too low to produce using fossil energy. There are two suitable temperature zones for methane fermentation: 35 °C and 55 °C (reviewed in Nakamura 2011). Choosing which 35 °C-fermented or 55 °C-fermented system uses depends on plants. More methane is produced by higher degree fermentation (55 °C) but the 55 °C-fermented system requires a lot of energy for heating fermentation tank. Thus, smaller plants are inefficient using the higher degree zones (reviewed in Nakamura 2011, Ogawa et al. 2003). Even in lower fermentation (35 °C), the smaller plant should have lower energy efficiency than larger one. Here, we have been trying to build small methane fermentation system using a thermal energy of hot spring in Naruko area, which is one of the famous resort areas in Japan. It has already been confirmed that the methane was produced in this system (Suzuki et al. 2012). In addition, the digested slurry from methane fermentation can be used as fertilizer of crops because there are many arable lands in Naruko area. Now this pilot plants are being tested (Suzuki et al. 2012).

For improving our proposed system, we should know how environmental impacts and cost including both initial inputs and operations are in comparison with the centralized methane fermentation system in hilly and mountainous. However, such a system, even similar-type methane fermentation system, has never existed. Thus, we cannot use the data of already-existed plants for our system and we must perform the estimation based on our results. For estimating both of environmental impacts, life cycle assessment (LCA) method has been widely used (Center for Environmental Information Service 1998, Jury et al. 2010, Roy et al. 2009). Within the methodological framework of LCA, environmental impacts will be carried out based on inventory of emissions and resources consumption. In addition, LCA method is suitable to evaluate the environmental impacts of an innovative technology (Jury et al. 2010).

In this study, the energy consumptions and global greenhouse gas (GHG) emissions of initial inputs and operations were estimated in the small methane fermentation system using hot spring. Both are useful as indicators of environmental impacts (Koga and Tajima 2011). And we also evaluated the costs of this system. The data of them were compared with that of the centralized methane fermentation system, assuming the introduction in such hilly and mountainous regions. We considered the effect of reduction of environmental impacts in hilly and mountainous regions.

Materials and Methods

2.1. Outline of our system

Fig. 1 illustrates outline of our proposed system and boundary of LCA. Garbage is taken into paper bag and brought to the methane fermentation plant by walk. Thus, we don't add environmental impacts and cost in transport of garbage to the estimation. Methane fermentation plant was heated up by hot spring. Methane produced by our system is used by gas lamp through desulfuration system. The slurry from methane fermentation is reserved in the tank for 1-3 days. After that, the slurry is transported in small truck and used as fertilizer. Evaluated energy consumptions and GHG emissions were drawn up in Fig. 1. We didn't count the energy and GHG that are used for production process on small track and broadcasting machine because these machineries are not only for our system.

2. Energy consumptions and GHG emissions from fuel and electricity consumptions

The consumption of fuel and electricity for operations in methane fermentation system such as transporting and broadcasting the slurry (see Fig. 1) were taken into account for energy consumptions and CO_2-equivalent GHG emissions. Total energy consumptions and GHG emissions were calculated using the index of energy consumptions and CO_2 equivalent GHG emissions (Table 1). In transport of the slurry, total gasoline consumption was estimated using fuel efficiency (8 km / L), load capacity (350 kg) and mean loading ratio (50 %) of small track and the assumed one-way distance (1 km). In broadcasting, total diesel consumption was estimated using fuel

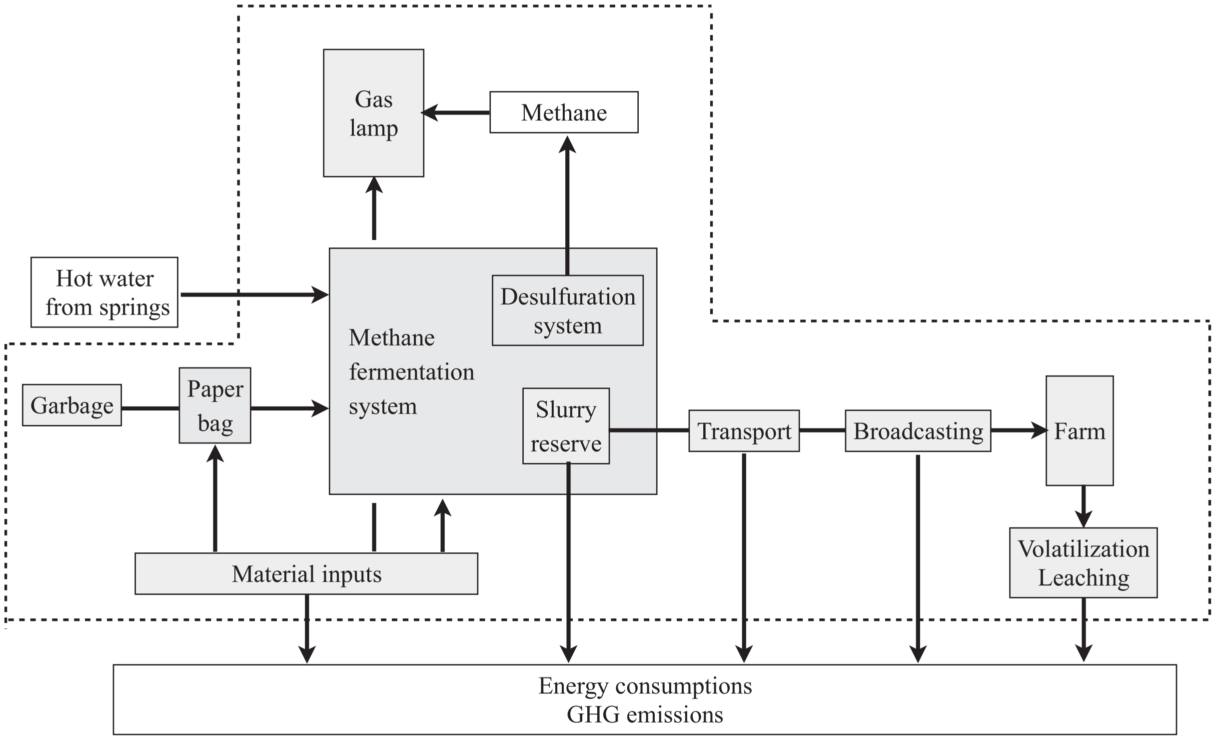

Fig. 1. Outline of the input-output flows of materials, energy and GHG emissions. Boundary is enclosed by dash lines.

Table 1. Equivalents for energy inputs and CO_2 emissions of fuels.

Fuels	Energy consumption MJ / L, kWh	GHG emission kg CO_2 / L, kWh
Diesel	37.8	2.59
Gasoline	34.6	2.32
LNG	54.6	2.70
Electricity	3.60	0.555

Means of 2004-2006. Data cited from Greenhouse Gas Inventory Office of Japan (2008).

efficiency (7.1 t slurry-broadcasting / L) and total broadcasting volume (60 L / day).

3. Energy consumptions and GHG emissions from input materials

Energy consumptions and GHG emissions from input materials such as desulfuration system, the tank for slurry, methane fermenter, gas lamp, monitoring device, balloon for methane storage and paper bag for garbage (Table 2) were estimated using energy and emission intensity data from Center for Global Environmental Research (2007). These intensity data derived from Japanese Input-Output tables (equivalent to a million yen). The actual expenditure for each material in our system was used for the estimations.

4. CH_4 emission from slurry reserve and volatilization and leaching from field.

CH_4 emission from slurry reserve was estimated using 0.0156 L CH_4 / kg-VS / day and 0.04 kg-VS / kg-slurry. To calculate total N_2O emissions from slurry-used field including indirect emissions from NH3 volatilization and NO_3 leaching, we used 0.0155 kg N_2O / kg-N applied as fertilizer (Greenhouse Gas

Table 2. Equivalents for energy inputs and CO_2 emissions of materials.

Materials	Material names on database	Energy consumption MJ / 10^3 yen	GHG emission kg x CO_2 / 10^3 yen
Desulfuration system	General machinery	47.4	3.66
Tank	Plastic products	44.9	2.79
Methane fermenter	Cast iron products	129	10.5
Gas lamp	General products	27.6	1.88
Monitoring device	Analyzer and measuring apparatus	21.5	1.39
Balloon	Tires and rubber	44.1	2.86
Paper bag	General paper products	41.8	2.42

Center for Global Environmental Research (2007).

Inventory Office of Japan 2008). The rate of N applied as fertilizer for the spinach cultivation was 90 kg N/ha. To sum up GHG emissions, global warming potentials factors of 1, 21 and 310 were used for CO_2, CH_4 and N_2O, respectively (Greenhouse Gas Inventory Office of Japan 2008).

5. Estimation of alternative effects of the system

Reduced energy consumptions and GHG emissions were evaluated by using methane and slurry from this system and garbage and hot springs. Methane produced in this system was evaluated as using instead of LNG. We used the actual data (produced methane: 0.3 m^3 / day) and energy consumption and GHG emission of using LNG (Table 1). Using of slurry as fertilizer reduces using chemical fertilizer that has energy consumptions and GHG emissions in the production and transport process. The slurry contains the nutrition components: 0.2 % N, 0.01 % P_2O_5, 0.15 % K_2O (w/v) from actual measurement data. The environmental impacts of reduced chemical fertilizer were estimated (150 MJ / kg, 10.5 kg CO_2 / kg using Center for Global Environmental Research 2007). Garbage typically was burned in Japan. The burning process has energy consumptions and GHG emissions. We assumed using garbage for methane fermentation reduces the electricity for burning. The environmental impacts of burning garbage are 0.643 GJ / t-garbage and 99.1 kg CO_2 / t-garbage. Using hot springs reduces fuel for heating methane fermenter in boiler (fuel efficiency 4 L diesel /h).

6. Estimation of costs in methane fermentation systems.

We evaluated the costs for our proposed methane fermentation plant and centralized larger-scale methane fermentation plant using the value in the report of Institute of Applied Energy (2006). The initial material input cost of materials of our proposed system was 750 thousand yen. Whereas, that of centralized methane fermentation plant is assumed as 70 million yen. Both construction costs are assumed as 20 % of initial costs and the depreciation periods in plants are assumed as 15 years. The maintenance costs of both plants are assumed as 5 thousand yen / t-garbage. The operation, repair and insurance costs per a year are assumed as 1, 3, 0.4 % of the initial material input costs, respectively. The staff cost is assumed as 3.5 million yen and the general administration cost is assumed as 80 % of it. In the centralized methane fermentation plant, at least three full-time staffs are needed but, in our system, no staff is needed because the manager of the hot spring can check system.

7. Evaluation of the introduction to the actual area

We evaluated our proposed system introduced in Naruko area in comparison with the centralized larger-scale methane fermentation system in same area. Naruko area, which has many hot springs located in Northern Japan, is one of famous resort areas. Naruko area is separated to five subareas and each area has many accommodations. Table 3 shows capacities of accommodation in the five areas. The total number of overnight guests per year is 230 thousands in Naruko area (personal communication with Naruko Machi-zukuri). It is suggested that 40 % of total capacity is used in Naruko area. It is assumed that one guest produces 300 g-garbage / day. In this evaluation, the centralized methane fermentation system is assumed as building nearby the already-existing disposal plants. The distances between each subarea and disposal site are also shown in Table 3.

Results

Energy consumptions, GHG emissions and costs in initial material inputs are shown in Table 4. The total cost of making our proposed system was about 1.6 million yen and gas lamp for using produced methane accounted for about half of this cost. Total energy consumption and GHG emission were 67.9 GJ and

Table 3. Capacity, amount of garbage and distance of five subareas in Naruko area.

Area	Capacity of accommodations	Amount of Garbage	Distance from disposal site
	pearsons / day	t / year	km
Kawatabi	448	20	9
Higashinaruko	855	37	12
Naruko	3339	146	15
Nakayamadaira	681	30	20
Onikobe	489	21	30
Total	5812	254	

Amount of garbage was estimated using 40 % of capacity of accommodations and garbage produced per a person (300 g/day).

Table 4. Costs and Environmental impacts of material inputs.

Fuels and Materials	Cost	Energy consumption	GHG emission
	10^3 yen	GJ	t CO_2
Desulfuration system	100	4.74	0.366
Tank	50	2.25	0.140
Methane fermenter	200	2.58	2.10
Gas lamp	800	2.21	1.50
Monitoring device	200	4.29	0.278
Balloon	200	8.81	0.573
Total	1,550	24.9	4.96

Costs were actual data. Environmental impacts were estimated using costs and the values of Table 2.

Table 5. Environmental impacts of operations in the proposed system.

Fuels and Materials	Fuel	Energy consumption	GHG emission	Energy consumption	GHG emission
		GJ / year	t CO_2 / year	GJ / t	t CO_2 / t
Paper bag	-	1.04	0.0606	0.476	0.0280
Slurry reserve	-	-	0.000599	-	0.000273
Transport	Gasoline	1.08	0.0810	0.498	0.0370
Broadcasting	Diesel	0.116	0.00715	0.053	0.00327
Volatilization and leaching	-	-	0.212	-	0.097
Total		2.24	0.361	1.03	0.165

Environmental impacts were estimated using the values of Table 1 and 2.

4.96 t CO_2, respectively. Balloon for the storage of methane has the highest values in both energy consumptions and GHG emissions.

Energy consumptions and GHG emissions in operating our system are shown in Table 5. The environmental impacts of paper bag were estimated using the values of Table 2. In slurry reserve and volatilization and leaching from field, only GHG emissions occurred. Total Energy consumption and GHG emission per a year were 2.24 GJ and 0.36 t CO_2, respectively and total Energy consumption and GHG emission per ton-garbage were 1.03 GJ and 0.165 t CO_2, respectively. Each value of operations is small because this system does not need the energy for heating methane fermenter using hot spring.

The summarized results from Table 4, 5 and the four alternative effects are illustrated in Fig. 2. The environmental impacts of initial material inputs (67.9 GJ, 4.96 t CO_2) were much larger than ones of operations per a year (2.24 GJ / year, 0.361 t CO_2 / year). The environmental impacts of four alternative reduced effects were evaluated to a large extent: e.g. 1.41-1290 GJ / year. The effects without using boiler for heating methane fermenter were extremely large (1290 GJ / year, 87.2 t CO_2 / year and 588 GJ / t-input, 39.8 t CO_2 / t-input).

Table 6 summarizes the alternative effects from Fig. 2. Both energy consumption and GHG emission of initial materials inputs were divided by 15 years because the depreciation period of this system is assumed as 15 years. Concerning the balances between the environmental impacts of initial and operations and the four alternative effects in energy consumptions and GHG emissions, the balances became minus except for the balance between inputs and only methane utilization (0.1 GJ / year, 0.504 t CO_2 / year). It is suggested that our system has the reduction effect of environmental impacts.

The costs of our proposed system and centralized larger-scale methane fermentation system are shown in Table 7. As well as energy consumptions and GHG emissions, the costs of initial inputs were divided by 15 years. Our system did not need full-time staff and electricity for plants. On the other hand, the centralized system was assumed to need two full-time staffs and the electricity. The differences in them were critical. The difference in total cost is extremely large. The garbage input capacities are different in 2 t / year of our system and 300 t / year of centralized methane emission but, in the costs per ton-garbage, our system was cheaper than the centralized system. The difference is about 30,000 yen.

The results from evaluation of the introduction of the system to Naruko area were shown in Table

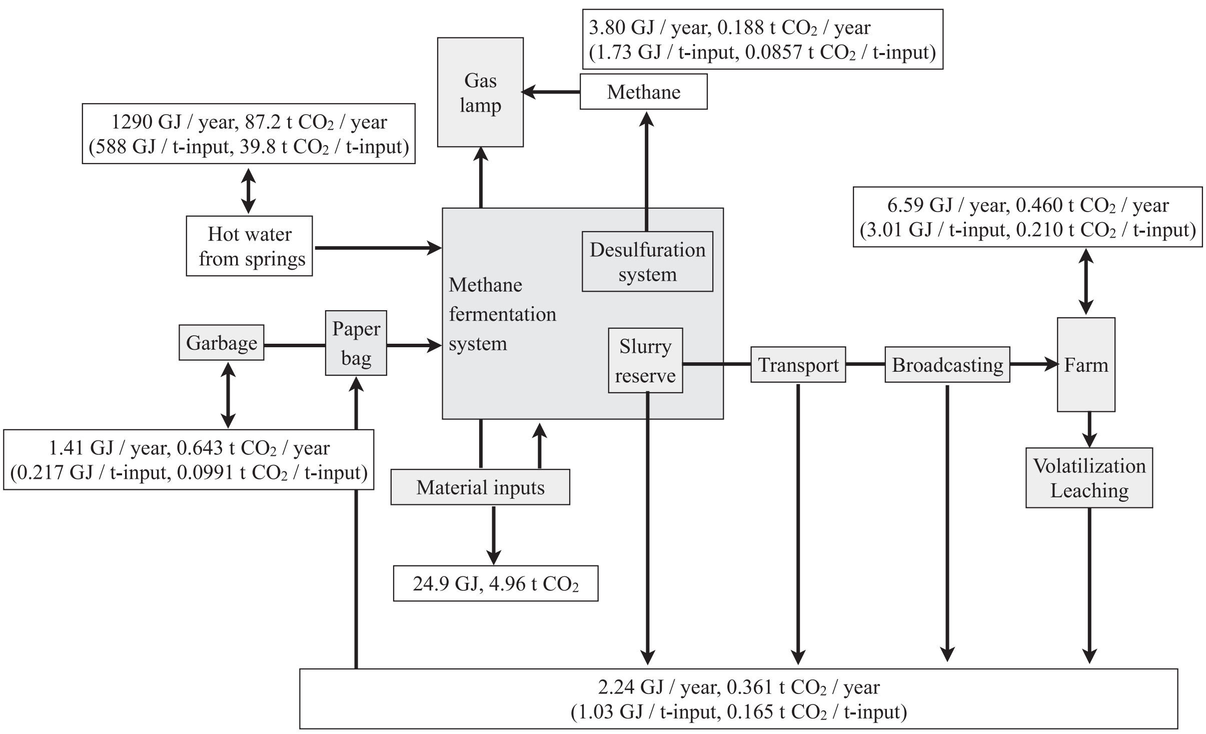

Fig. 2. Energy consumptions and GHG emissions and alternative effects.

8. Using the capacities of accommodations and the value of 300 g-garbage / person day, it was assumed that 254 t-garbage per year were treated by methane fermentation systems (Table 3). The number of our system needed 69 plants. The cost per one plant is much lower than the centralized system (Table 7) but, in the cost in the total area, the cost of our system was half of the centralized system. We assumed the centralized methane system has a cogenerating system from methane to electricity. The apparent values of electricity have already reduced the amount of electricity from methane. Thus, the value of methane utilization of the centralized system was zero. In addition, there are energy consumption and GHG emission in the slurry treatment. The balances in energy consumptions and GHG emissions are -347 GJ, -2.50 t CO_2 / year of our proposed system and 216 GJ, 41.1 t CO_2 / year of centralized system.

Discussion

In this study, we evaluated the environmental impacts and cost of our proposed methane fermentation system using hot spring in hilly and mountainous regions. And those data of them were compared with that of the conventional larger-scale methane fermentation system. We used LCA methods, which are suitable to evaluate an innovative technology, using the data from our system and the inventory data. We evaluated the environmental impacts of initial inputs (67.9 GJ, 4.96 t CO_2) and ones of operations (2.24 GJ / year, 0.361 t CO_2 / year) in this system. Using methane and slurry from methane fermentation system using hot spring without fuel for heating up, our proposed system has a potential of significant reduction of environmental impacts. Assuming the actual area on hilly and mountainous regions, not only the environmental impacts but costs were more reduced than the centralized methane. It has been considered that

Table 6. Environmental impacts of initial, operation and alternative effects.

	Energy consumption GJ / year	GHG emission t CO_2 / year
Initial	4.53 (67.9 GJ)	0.331 (4.96 t CO_2)
Operations (including slurry-using process)	2.24	0.361
Methane utilization	-3.80	-0.188
Slurry utilization (without using chemical fertilizer)	-6.59	-0.460
Using Garbage (without burning using electricity)	-1.41	-0.643
Using Hot springs (without using boiler)	-1290	-87.2

Environmental impacts of initial were divided by 15 years. Total impacts are noted in brackets.

Table 7. Costs of the proposed system and centralized system.

Costs	Proposed system 10^3 yen	Centralized System 10^3 yen
Initial	60 (750)	5600 (70000)
Maintenance	10	1500
Labor	0	7000
Electricity	0	1450
Others	30	8400
Total	100	23950
per t-input	50	80

Costs of initial were divided by 15 years. Total costs are noted in brackets.

Table 8. Evaluation of introduction of two methane fermentation systems to Naruko area.

	Proposed methane fermentation system	Centralized methane fermentation system
	10^3 yen, GJ, t CO_2 / year	10^3 yen, GJ, t CO_2 / year
Number of required systems	69	1
Costs	12,700	20,320
Energy consumption		
Initial	312	114
Collection	0	6.98
Running	0	7.25
Methane utilization	-262	0
Slurry treatment	-397	87.3
Balance	-347	216
GHG emission		
Initial	23.0	8.33
Collection	0	0.489
Running	0	1.02
Methane utilization	-13.0	0
Slurry treatment	-12.5	31.3
Balance	-2.50	41.1

Environmental impacts and Costs of initial were divided by 15 years.

to establish any bioenergy system is difficult in hilly and mountainous regions in Japan (Hong et al. 2009, Roy et al. 2009) but our proposed system could be an effective system in such areas.

We consider the reason why these positive effects of reduction in environmental impacts are four things: 1) using hot spring for heating methane fermenter, 2) on-site plants (the distance of garbage transport is zero), 3) using methane as fuel directly, 4) using slurry as fertilizer. Concerning environmental impacts and cost, most papers of methane fermentation system have reported the key of reduction in environmental impacts and cost is to build large-scale plants (Hong et al. 2009, Roy et al. 2009). However, based on our results, small-scale methane fermentation system should be an effective system for both environmental impacts and cost.

In our research, we evaluated the significant reduction of environmental impacts and cost in comparison with the centralized system but we validated the effects to introduce our system in only Naruko area. It is not directly suggested that the environmental impacts and cost are reduced using our system in the other resort areas. However, Naruko area is typically Japanese traditional resort area. The similar resort areas, which have hot spring located in hilly and mountainous regions, were abundant in Japan. In such areas, the effects on reductions may be similar to this estimation.

The centralized methane fermentation system assumed in this research is relatively small in large-scale plants. We considered it is difficult to build the much larger-scale plants in hilly and mountainous regions such as Naruko area but, if the garbage was collected from the larger area, the centralized system should be more effective on the reduction of both environmental impacts and cost. Furthermore, we must consider how size our proposed system is effective. We should accumulate the more data for sensitive analysis for this.

In conclusion, it has been considered that to introduce any bioenergy system is difficult in hilly and mountainous regions in Japan but our proposed methane fermentation system using hot spring could be an effective system in such regions. These results should facilitate to rethink about the establishment of small biomass use system and our proposed system should be one of key techniques in the reduction of environmental impacts using biomass in hilly and mountainous regions.

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