EVALUATION SYSTEM OF CO_2 EMISSION REDUCTION BY IMPLEMENTING INTEGRATED METHANE FERMENTATION SYSTEM AS A MUNICIPAL ORGANIC WASTE RECYCLING SCHEME IN TOKYO BAY REGION

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This paper focuses on the evaluation of CO_2 emission reductions that can be achieved by implementing integrated methane fermentation systems in sewage treatment plants (STPs) as a municipal organic waste recycling scheme in Tokyo Bay Region. Target organic wastes are sewage/sanitary sludge (simplified as sewage sludge in the following article due to the insignificant quantity of sanitary sludge in STPs), food wastes from household, food distribution and manufacturing sector, livestock excreta and agriculture waste. Geographical Information System (GIS) is utilized to develop a database platform which provides spatial and attribute data on the flow of organic waste matters. Two cases designed for evaluations are differentiated by the types of organic wastes and different organic wastes collecting boundaries.

Key Words: *municipal organic wastes, integrated methane fermentation system, sewage treatment plants (STPs), Geographical Information System (GIS), energy recovery, CO_2 emission reduction*

1. INTRODUCTION

Tokyo Bay Region, or Kanto Region, includes Metropolis of Tokyo, Kanagawa Prefecture, Chiba Prefecture, Saitama Prefecture, Gunma Prefecture, Tochigi Prefecture and Ibaraki Prefecture. Human habitations, as well as commercial, industrial, agriculture and livestock activities have directly or indirectly created negative environmental impacts such as water and solid wastes pollutions in Tokyo Bay Region. Besides water body contamination and landfill shortage problem, CO_2 emission problem is also one of the urgent crucial problems due to the commitment to Kyoto Protocol. In addition, aiming for a sustainable development, Japan has put its eyes on the issue of sustainable energy supply, which include recovering biomass energy, solar energy and wind energy to alleviate the energy dependency upon imported fossil fuels and the pollutions caused.

Among all types of renewable energies, the potential of recovery energy from biomass is widely recognized, and efforts in this field have been made by various institutes and government sectors. Four driving forces of creating a biomass recycling society include mitigating global warming effect, creating a sustainable society, revitalizing the economic by shifting the conventional type of mass-consuming-and-production industries to new type of biomass-related recycling industry to increase the competitiveness internationally, and invigorating agriculture, forestry and fishery industries by the biomass-related industry[1].

In the book of "Biomass Nippon- Towards the Revitalization of Japan"[2], reusable biomass is categorized into four types by their origins, including biomass as waste matters (municipal solid waste, sewage sludge, industrial waste, waste wood from construction activities, etc.), unutilized biomass (inedible parts of crops, etc.), resource/energy-oriented biomass (crops for producing rapeseed oil and fodder, etc.), and lastly, genetically engineered biomass (genetically improved crops, etc.). By fully recovering and reutilizing this biomass as energy, about 15% of current fossil fuel demand could be substituted, and at most 15% of CO_2 emission reduction from energy demand can be expected.

Because of high population, commercial and industrial activities, Tokyo Bay Regions is overflowing with unrecovered waste biomass resources, especially sewage sludge and food waste from household. In this research, based on the assumption that no municipal organic wastes are currently recovered in this region, integrated methane fermentation system is chosen as the resource-recycling technology as a municipal organic waste recycling scheme due to the suitability of treating organic solid wastes with high moisture content, in the meanwhile, achieving the goal of energy recovery in the region. To evaluate the environmental impacts, a spatial database platform on the distributions of organic waste matters in Tokyo Bay Region is developed. Policy options such as locations of implementation and organic waste collecting boundaries are incorporated. The recovery of energy and corresponding CO_2 emission reduction effects are assessed as indicators for the suitability and significance of policy enactment.

2. METHANE FERMENTATION SYSTEM

Methane fermentation process is one of the oldest processes for stabilizing sludge. It has been and remains to be one of the major technologies for stabilizing of concentrated sludge from sewage wastewater treatment and industrial wastewater due to the merits of less sludge or residue production because of low bacteria growth rate, ability of disinfection, low energy consumption during treatment, and energy recovery; however, recovery of biogas as a energy source was not concerned until the high global warming potential of methane gas was identified and the focus of energy recovery emerged . The applications have been extended to treatments of other high moisture and even diluted organic wastes such as sewage wastewater.

Integrated methane fermentation process, which different from single organic waste input type of system, ferments mixed type of organic wastes in a single digestion tank to produce biogas. Because integrated methane fermentation application is still not a common practice, estimation of biogas productions for macro-scale type of planning is still a quest.

In general, there are two types of methane fermentation processes, which are mesophilic (35°C) and thermophilic (55°C) conditions. Thermophilic methane fermentation process is widely recognized as having a higher loading rate and degradation rate for stabilizing organic waste and a better performance in disinfection and inhibition of the growth of pathogen. Methane production potential is commonly acknowledged to be primarily related to several factors including type of organic wastes, digestion temperatures and ammonia inhibition, which are discussed as below:-

- *Chemical nature of organic matters*

The potential of methane production was found related to different types of organic matters. In the research accomplished of Lay & Li[4], the potential of methane gas production of organic wastes was categorized into three groups, which are protein and lipids, starch, and cellulose. Protein and lipids has the highest potential and cellulose group has the least. In addition, methane gas content was found higher by adding meat bun[5] and biogas production was increased while waste oil from food industry was included (interview result from Kajima Corporation).

- *Digestion temperatures and inhibition effect*

Methane production in thermophilic condition is theoretically higher than mesophilic condition under no inhibition condition[6]. According to the research outcomes from Kiyohara & Miyahara[7], the production rate of volatile acid and methane were found twice time higher and total biogas production was at least 10% higher than another research in mesophilic condition which was done by Li and Noike. Besides,

Table 1 Summary of reference research papers

Researchers	Temperature	Organic Matters	Research Objective	Year
Jiunn-Jyi LAY et. al.	Mesophilic	Municipal solid waste, including sludge cake	To investigate the methane fermentation characteristic of municipal solid wastes by chemical nature and moisture content	1996
Chun-Feng CHU et. al.	Mesophilic/ Thermophilic	Sewage sludge	To examine the degradation ability of palmitic acid and acetate in both temperatures	1997
Yuukou KIYOHARA et. al.	Thermophilic	Dehydrated sewage slugde	To examine the effects of sludge detention time on the degradation ability of organic compounds and methane production.	1998
Shigeki FUJISHIMA et. al.	Mesophilic	Dehydrated sewage sludge	To investigate the effects of solid contents in sewage sludge on the degradability of organic compounds and methane production.	1999
Yoshio OKUNO et. al.	Mesophilic/ Thermophilic	Dehydrated sewage sludge, food waste	To examine the degradability ability and methane production by varying sludge to food waste ratio in different temperatures.	2003
OTOKONARI et. al.	Thermophilic	Food wastes	To investigate the performances of thermophilic methane fermentation process, including biogas production, methane gas composition and wastewater quality by different types of food wastes biogas.	2003
Hiroshi ISHII et. al.	Mesophilic	livestock excreta, used papers, dog food and bread	To investigate the performances of methane fermentation process to the preparation of seed sludge.	2003
Yukimashi OGAWA et. al.	Mesophilic/ Thermophilic	livestock excreta, food & agriculture wastes	To evaluate the biogas energy generation performance in Yagi Bio-Ecology Center.	2004

operation performance results in Yagi Bio-Ecology Center showed that thermophilic condition had a better biogas production result than mesophilic condition[8].

However, the research paper of Chu & Miyahara[6], showed that the degradation rate and maximum loading rate of fatty acid (palmitic acid) were found higher in thermophilic than mesophilic condition but total amount of methane productions in both conditions were almost the same. In addition, for researches which related to organic wastes with high ammonia contents, methane production was found having higher tendency to be inhibited in thermophilic condition, although the degradation of complex organic compounds was found higher than mesophilic condition[9]. Regarding the ammonia inhibition effect on methane production, inhibition was observed for NH_4^+-N concentrations vary from 2,500 mg/l to 3,800 mg/l in different research outcomes[9,10,11] for mesophilic condition, and from 2,500 mg/L in thermophilic condition[9].

In this research, thermophilic methane fermentation process with higher organic loading rate and degradation rate is chosen as the digestion condition for treating large amount of sewage sludge and other organic matters due to the major consideration of space constraints for implementation of facilities. Major concerns of thermophilic condition are ammonia inhibition, higher energy consumption and poor supernatant quality[9,12] for heating requirement. According to existing research outcomes and surveys of makers of methane fermentation system which have been carried out (please refer to Section 5(1) a)), several presumptions are made in this research, which are discussed as below: -

(1) Estimation of biogas production

Biogas production is found primarily relating to types of organic wastes and digestion conditions. Because of the application of integrated methane fermentation system to treat different type of organic wastes, biogas production estimation is simplified to be related to input amounts of carbon of different type of organic wastes. According to data collected from maker surveys, equations for biogas estimation which have a function of carbon input are developed. The effect of digestion condition to biogas production is presumed having less impact than type of organic wastes and is ignored due to the limitation of unbiased data regards the relationship among biogas productions, types of organic matters and digestion conditions in surveys. Please refer to Section 5(1) b) for detailed.

In addition, ammonia concentration was observed under inhibition threshold in thermophilic condition for sewage sludge which has Total Solid (TS) below 5%[7], and under control for food wastes (interview result from Kajima Corporation).

(2) System self-consumption of energy

Surveys on makers of methane fermentation systems also showed that all plants are able to be energy self-supported and surplus energy is available (especially methane fermentation plants of food wastes). In addition, according to the research report of Yagi Bio-Ecology Center[8], one-third of electricity which is converted from biogas is currently used for major methane fermentation facilities including pretreatment and digestion tank heating, and two-third of that is for the operation of dehydrator, supernatant treatment and compost facilities. Only 20% of the heat converted is reutilized mainly for digestion tank heating. With the consideration of fully recovery situation of organic wastes as biogas and liquid fertilizer (no post treatment), about 70% of surplus energy can be distributed.

In this research, since STPs are presumed as the locations of implementations, supernatant is assumed to be returned and treated by sewage treatment facilities which have enough capacities to handle the additional nutrient loads. As a result, 30% of energy self-consumption for methane fermentation system is presumed in our calculation.

3. REVIEW OF RESEARCH PAPERS ON DEVELOPING DATABASE PLATFORM ON ORGANIC WASTE MATTERS

There is several research papers focus on the development of database platform in order to study flows of organic waste mattes and evaluate environmental impacts as results of recovering different types of waste materials by various resource-recycling technologies available nowadays.

In our previous research paper which accomplished in year 2003 (Morioka & Fujita[3]), the changes in flows of organic matters in Muko River Basin in year 1974 and year 2000 due to the urbanization were investigated. Besides, in the same year another research paper (Kurisu & Morioka[13]) which focused on an integrated recycling system as the organic matters recycling infrastructure in Muko River Basin was published, and the development of spatial database platform regarding flows of organic matters in Muko River Basin by the application of GIS was discussed intensively by Tanji & Morioka[14].

Extending the above research accomplishments and intending to focus on the implementation of resource- recycling technologies depending on regional properties to recover organic matters as energy sources, Fujita et. al.[15] developed a spatial database platform on flows of organic matters and did a case study to evaluate the potential of implementing small scale of methane fermentation systems in Saitama Prefecture and Arakawa River Basin in Tokyo Bay Region.

On the other hand, Shimizu et. al.[16] utilized GIS to develop a spatial database for Life Cycle Assessment on environmental impacts of CO_2, CH_4 and N_2O emissions as well as the amount of landfilled solid waste of food wastes from household, food distribution and manufacturing, and livestock excreta in Chiba Prefecture. Origins of target organic wastes were identified by digitalizing statistical data and the locations of treatment facilities such as composting and incineration plants were allocated for the determination of environmental impacts through transportation. In addition, the inventory of major treatment processes such as dehydration, incineration, and composting processes was created to obtain direct and indirect environment impacts caused.

4. PROCESS OF DEVELOPING DATABASE ON FLOWS OF ORGANIC WASTE MATTERS IN TOKYO BAY REGION

Our research intends to extend the above mentioned case studies, which studied and evaluated regional environmental impacts from municipal organic wastes in Saitama and Chiba Prefecture to the whole Tokyo Bay Region by developing a more comprehensive spatial database platform.

(1) Selection of target organic waste matters and implementation locations for integrated methane fermentation systems

In this research, corresponding to the research outcome of dominated organic wastes from Morioka & Fujita[3], sewage sludge, food wastes from household, food distribution and manufacturing sectors, agriculture waste and livestock excreta are selected as targets for evaluation.

Sewage treatment plants (STPs) in Tokyo Bay Regions are chosen as locations for system implementations for the first stage of evaluation. Although the cost of implementation is not taken into account up to this stage, the fact of limited land spaces and high land prices in Tokyo Bay Region are not totally ignored. Thus, fully utilizing available public spaces is considered as a rational assumption. In addition, by considering the difficulty of transporting sewage sludge from wastewater treatment process, STPs as locations of implementations are presumed.

(2) Establishment of spatial database platform

Geographical Information System (GIS) is applied to develop a spatial database with qualitative and quantitative data corresponding to the regional properties. To investigate and analyze the flows and distribution of organic wastes available in Tokyo Bay Region, GIS which has functions of creating and visualizing spatial data, spatial searching, data overlaying, buffer operating, and network analysis, serves as the database platform management tool.

In order to standardize different types of waste biomass available for integrated resource-recycling process and identify the origins of pollutants in Tokyo Bay Region for analysis and assessment, distributions of target organic waste matters are expressed in term of carbon (C), nitrogen (N) and phosphorous (P) as pollutant indicators.

a) Data collection and processing

Before the application of GIS for spatial analysis can be done, basic statistical data are required for the determination of generations and flows of target organic wastes. Organic waste generations in target sectors are obtained as procedures below: - (Please refer to Table 2 & Figure 1)

- *Sewage sludge*

  Statistical data regards locations of STPs, treatment capacities, sludge productions, energy consumptions, and influence and effluence quailties are received in point data format (please refer to Figure 2 for the locations of STPs and corresponding sludge quantities). By identifying the moisture content and compositions of carbon, nitrogen and phosphorous in sludge, total amounts C, N, P from sludge in each STPs are determined.

- *Food waste from household sector*

  Statistical data about population, the number of households and housing types are gathered in 1km grid cell format. With the specific general waste generation rate (per person yearly) and organic composition as well as C, N and P compositions, distributions of C, N and P from household are determined in 1 km grid cell. Due to the limitation of data, general waste generation rate is obtained by averaging the data from Chiba Prefecture and Saitama Prefecture. Please refer to Figure 3 for the household food waste distribution.

- *Food waste from food distribution sector*

  Statistical data include the number of stores, sales area and yearly sales amount are collected in 1km grid cell format. The amount of general waste is calculated based on the yearly sales amount, and the amount of organic waste is determined by the organic composition in general waste (please refer to Figure 4). C, N, P contents are determined in the same pattern as other organic wastes. The specific general waste generation rate is the average value of Tokyo and Saitama Prefecture and organic com-

Table 2 Parameters for calculation of C, N, and P

	Target Organic Wastes	C- Content (%) Dry-based	N- Content (%) Dry-based	P- Content (%) Dry-based	Moisture Content (%)
1	Sewage/sanitary sludge [9,17,18]	34.80	5.60	2.01	Ave: 99.22
	Food wastes from				
2	Household [9,19,20]	47.60	3.27	-	70
3	Food Distribution [9,19,20]	47.60	3.27	-	70
4	Food Manufacturing [21]	20.02	1.00	-	70
5	Agriculture waste [22,23]	40.90	0.40 - 2.10 (/wet-t)	-	30
6	Livestock excreta [24,25]	35.10	0.51- 2.43 (/wet-t)	0.06 – 0.42 (/wet-t)	83

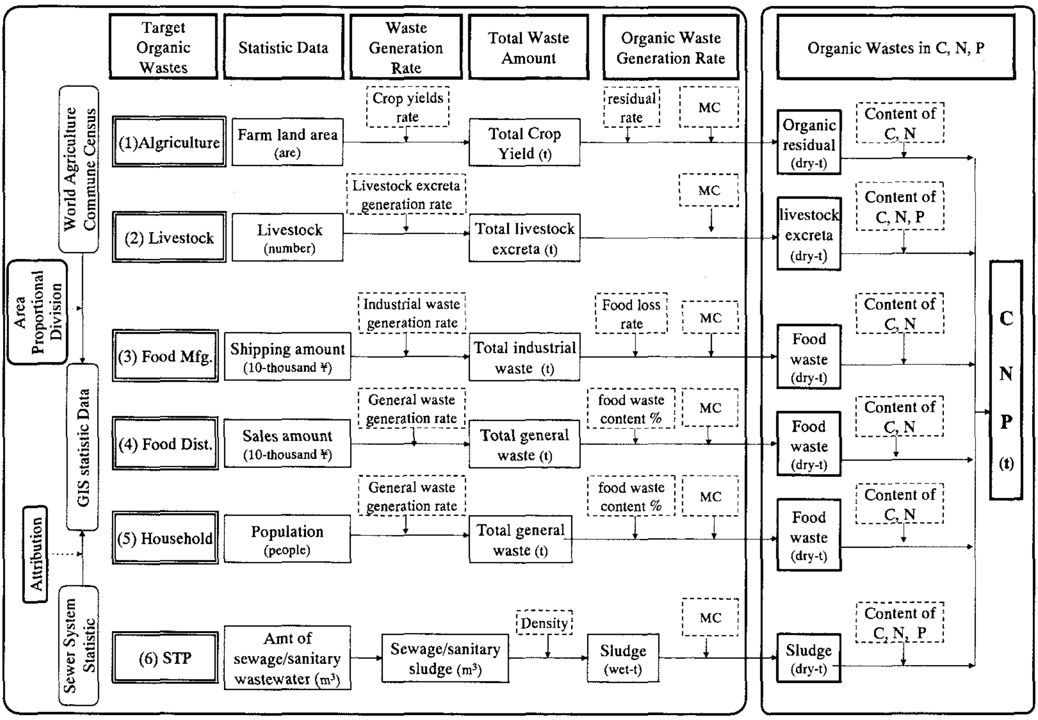

Figure 1 Calculation process for C, N, P

position is assumed to be the same as household sector.

■ *Food waste from food manufacturing sector*

The number of factories, workers and yearly shipping amount are collected in 1km grid cell format. General waste is calculated based on the yearly shipping amount, and the amount of organic waste generated is determined according to the food loss rate (please refer to Figure 5). Quantities of C, N, and P are identified in the same procedure as food wastes from other sectors. Same as food distribution sector, industrial waste generation rate is determined by averaging the values of Tokyo and Saitama Prefecture.

■ *Agriculture waste*

Types of crops and areas of covering are obtained from statistical data in commune units based on the World Agriculture Commune Census. The total amount of crop yields from paddy, wheat and vegetable are calculated based on the area of crops. Organic residues are identified from the average residue rate in Tokyo Bay Region (please refer to Figure 6). In addition, amounts C, N and P are calculated depending on the types of crops.

■ *Livestock excreta*

Data regard types and numbers of livestock in Tokyo Bay Region are identified in commune units based on the World Agriculture Commune Census. The quantities of livestock excreta from milk cows, meat cows, swine and poultry are acquired based on the number of livestock in each category (please refer to Figure 7). C, N and P are

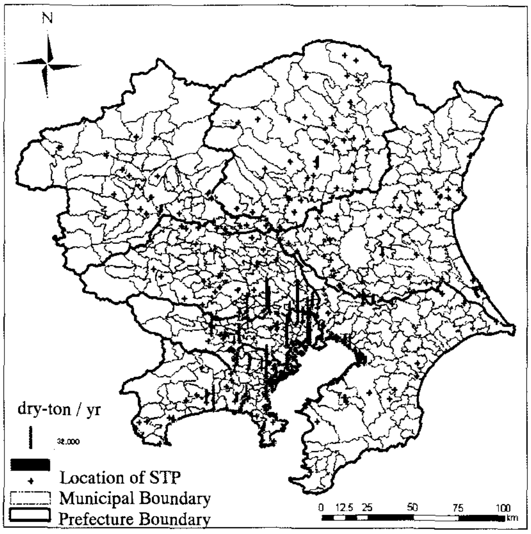

Figure 2 Locations of STPs and sludge quantities

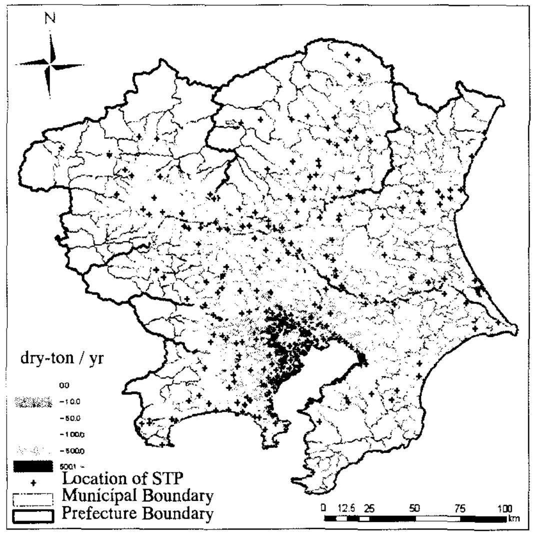

Figure 3 Food waste from household

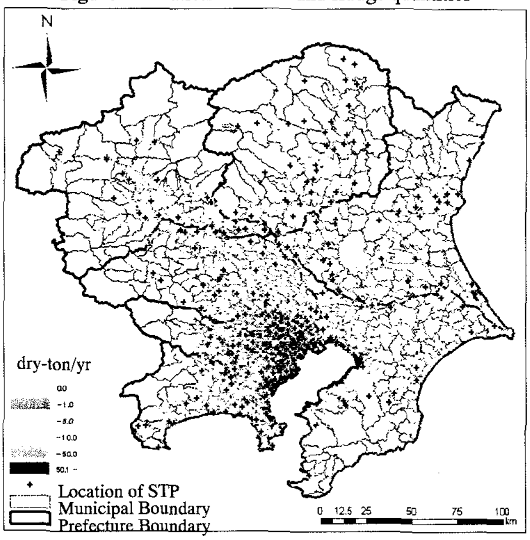

Figure 4 Food waste from food distribution sector

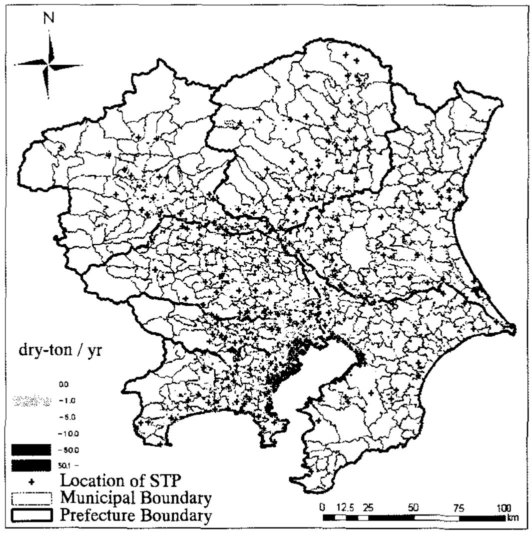

Figure 5 Food waste from food manufacturing sector

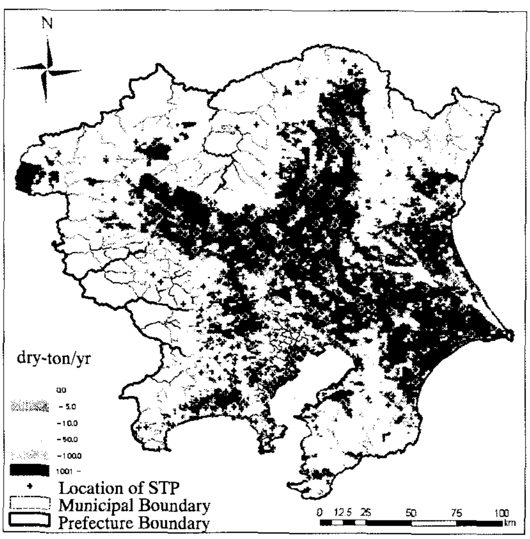

Figure 6 Agricultural waste

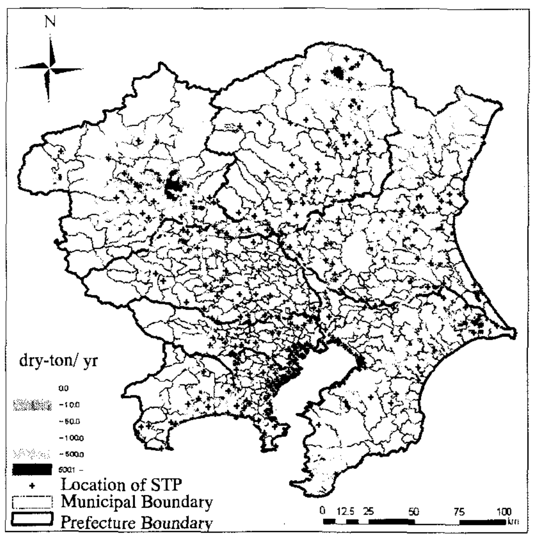

Figure 7 Livestock excreta

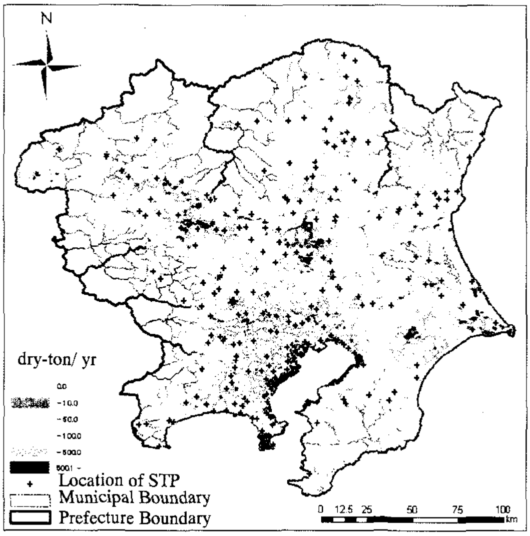

Figure 8 C-distribution from 6 sectors (1 km-grid)

calculated depending on the types of livestock.

b) Overlaying of database

Besides data from household, food distribution and manufacturing sectors which original database are received in grid cell format, data of other target sectors needed to be converted to digital format.

According to the availability of data on sludge productions, 209 STPs are selected as implementation locations for integrative methane fermentation systems. Point data of sewage sludge from STPs are converted to 1 km grid cell; on the other hand, data from agriculture and livestock sectors are first developed in polygon format, followed by converting to 1 km grid cell. Total C, N and P generations from six sectors in Tokyo Bay Region are overlaid after all the data is digitalized in 1 km grid cell (please refer to Figure 8 for the overlaying result of C distribution).

Furthermore, information on demographic, socio-economic, industry, and targeted organic wastes in Tokyo Bay Region are fragmented into 5 km grid cell database for analysis purpose. This is due to the consideration of collecting boundaries of organic wastes for integrated methane systems in STPs.

With the application of GIS, 1 km and 5 km grid cells which consist of selected 209 STPs are picked up together with the corresponding quality and quantity information of organic wastes from 6 sectors. In addition, in the case that more than one STP are fallen within a grid cell, except sewage sludge, other available organic waste inputs in the grid cell are divided equally to each system in STPs.

5. CASE STUDIES IN TOKYO BAY REGION

Two cases, which are differentiated by types of organic waste matters collected, are designed in order to evaluate CO_2 emission reductions that could be achieved in Tokyo Bay Region through energy recovery by implementing integrated methane fermentation systems in STPs. Thermophilic condition is selected due to higher organic loading rate and degradation rate for saving spaces of implementations.

- *Case 1* (please refer to Figure 9)
  This case considers integrated methane fermentation process of sewage sludge in 209 STPs with food waste from household, food distributing & manufacturing sectors.
- *Case 2* (please refer to Figure 10)
  Different from Case 1, besides sewage sludge and food waste from household, food distributing & manufacturing sectors, agriculture waste and livestock excreta from rural area are also included.

In addition, no waste biomass recovery practice in this region which is related to energy recovery is assumed. Organic wastes collecting boundary are set to 1 km & 5 km grid cell from STPs for both cases to evaluate the significance of collection boundaries versus the recovery of organic wastes and energy. 1 km & 5 km grid collecting boundaries are settings for our first stage evaluation. Small scale circulation

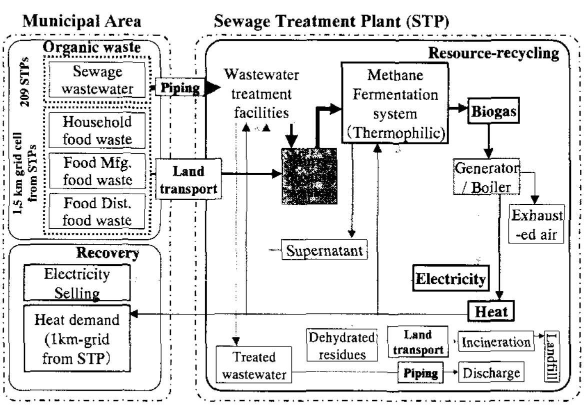

Figure 9 CASE 1

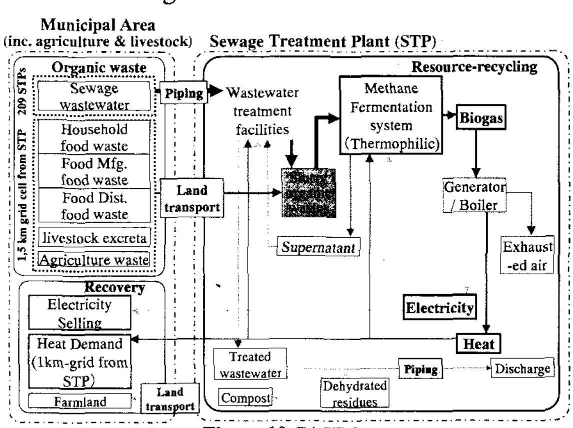

Figure 10 CASE 2

systems are considered in order to avoid problems such as stock yard shortage or negative feedbacks from neighborhood residential areas.

CO_2 emission reductions that can be achieved are based on biogas productions from integrated methane fermentation systems and energy that can be reutilized. Moreover, CO_2 emissions during the construction of facilities, transportations of organic wastes to STPs, final residues from STPs to landfill or other further recycling activities as well as landfill impacts are not taken into considerations in this paper.

(1) Estimation of biogas production

Most of the current methane fermentation systems in practical are focusing on handling single type of organic waste. Thus, paper surveys and interviews with makers of methane fermentation systems have been carried out for actual operation data in order to estimate biogas productions for integrated methane fermentation systems which treat mixed types of organic wastes.

a) Maker survey

15 makers are involved in the paper survey and more than 20 plant data are collected. Three types of digestion conditions are concluded from the surveys, including thermophilic, mesophilic and two-stage processes. Two-stage process in the survey is a system which combines two digesting conditions which mesophilic condition is followed by thermophilic condition. Due to the scarcity of research results for performance of two-stage process, data from this system are excluded in the estimation of biogas production in this research.

b) Equations for estimation

Due to the limitation of data and bias of data regarding types of wastes and digestion conditions (commonly thermophilic condition is applied to treat food waste and mesophilic condition for livestock excreta), integrative relationships among biogas productions with various types of input organic sources and digestion conditions are failed to be examined. Thus, in our research types of organic wastes are considered as a major factor in biogas productions, and the effect of digestion temperatures is ignored in the estimation of biogas production.

From the data collected, biogas production potentials for different types of organic wastes are categorized to two groups, which are high biogas production potential and low biogas production potential groups (please refer to Table 3). For systems which received more than one type of organic waste, grouping is done depending on the majority of waste type. Organic waste which belongs to the group of high biogas production potential is food waste; whereas livestock excreta is categorized as low potential group. In addition, estimation of biogas production is simplified as a function consists of substitute variable of carbon input from organic wastes of different biogas production potentials. For the necessary of this research, sewage sludge and agriculture residue are considered belonging to low potential group.

According to the data from surveys, regressions regard relationships between biogas production and input organic carbon of high and low biogas production potential groups are performed (please refer to Figure 11). From a statistical stand point, functions of carbon input fit biogas productions very well for both high/low biogas production potential groups, which 97% and 99% of the variability are explained. Thus, biogas productions for integrated methane fermentation systems in this research are estimated based on the equations below:-

- Organic waste with high biogas production potential (include food wastes from household, food distribution and industrial sector)

Table 3 Types of organic waste inputs and system digestion conditions in maker surveys

	Type of Organic Waste Input (Plant Data for High Potential of Biogas Production Group)	Fermentation Condition		Type of Organic Waste Input (Plant Data for Low Potential of Biogas Production Group)	Fermentation Condition
1	Food waste	Thermophilic	1	Livestock excreta	Thermophilic
2	Food waste	Thermophilic	2	Livestock excreta	Thermophilic
3	Food waste	Thermophilic	3	Livestock excreta	Mesophilic
4	Food waste	Thermophilic	4	Livestock excreta	Mesophilic
5	Food waste	Thermophilic	5	Livestock excreta	Mesophilic
6	Food waste	Thermophilic	6	Livestock excreta	Mesophilic
7	Food waste	Thermophilic	7	Livestock excreta	Mesophilic
8	Food waste	Mesophilic	8	Livestock excreta	Not Available
9	Food waste (majority) + Sanitary wastewater	Thermophilic	9	Livestock excreta (majority) + Food waste	Mesophilic
10	Food waste (majority) + Sanitary wastewater	Thermophilic	10	Livestock excreta (majority) + Agriculture waste + Food waste	Mesophilic
11	Food waste (majority) + Construction waste	Mesophilic			
12	Food waste (majority) + Livestock excreta + Food oil	Mesophilic			

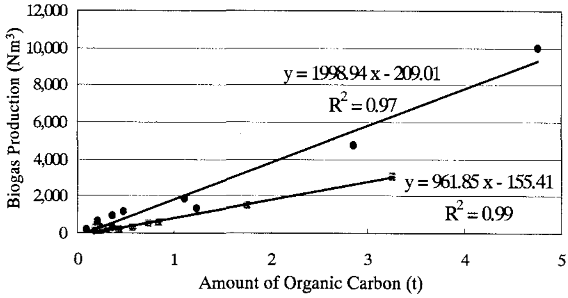

Figure 11 Regressions for high/low biogas production potential organic waste groups

$$BP_H = 1998.94*C_h - 209.01 \quad (1)$$

where BP_H is the yield of biogas for high potential group (Nm^3), and C_h is the input of organic carbon with high biogas production potential (ton-C)

- Organic waste with low biogas production potential (including sewage sludge, livestock excreta & agriculture waste)

$$BP_L = 961.85*C_l - 155.41 \quad (2)$$

where BP_L is the yield of biogas for low potential group (Nm^3), and C_l is the input of organic carbon with low biogas production potential (ton-C)

(2) Determination of energy recovery

Biogas produced is converted to electricity and heat with energy production efficiency of 5,500kCal/ Nm^3 -biogas and conversion efficiencies of 25% and 40% respectively[26]. To evaluate the overall CO_2 emissions that can be reduced from the recovery of energy by implementing the systems, energy self-consumptions of systems are not considered as a part of the energy recovered. Furthermore, energy required for the operation of STPs are priority while considering the surplus energy that can be distributed to household sectors (please refer to Figure 12).

a) System self-consumption of energy

Self-consumptions of energy for methane fermentation systems vary depending on the components

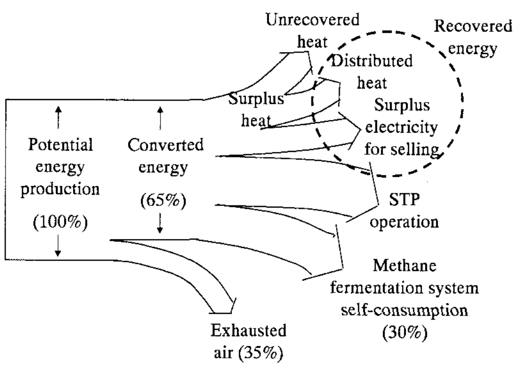

Figure 12 Energy recovery pattern

and additional treatments facilities equipped. The major energy consumption processes include pretreatment (separating and grinding process), heating of digesters, operation of generators and supernatant treatment process. Besides digestor heating energy, supernatant treatment is another main process that consumes a large portion of energy that converted from biogas.

In this paper, since STPs are the locations of implementations, supernatants are presumed to be returned and treated in STPs. In addition, all STPs are assumed having the ability to treat additional nutrient loads. According to the research outcome by Ogawa et. al.[6], 30% of energy converted from biogas is assumed as the requirement for self consumption of systems in our calculation.

b) Energy consumptions in STPs

From the sewer statistics of Japan, STPs are currently consuming electricity, heavy oil, kerosene, town gas, propane gas, diesel, gasoline and biogas as energy sources. Energy consumption of each plant is identified in reference to their current consumption patterns. Current energy requirements for sludge treatments are excluded since methane fermentation systems are the substitutions of sludge treatment facilities in STPs. In addition, extra energy consumptions in wastewater treatment facilities due to the additional ammonia loads from supernatant are not concerned in this calculation.

c) Electricity and heat recovery from household demands

After the consideration of energy consumptions for methane fermentation systems and STPs, surplus energy (if any) in form of electricity and heat can be distributed to satisfy household demands. Surplus electricity can be reutilized without any spatial constraint but the recovery of heat is assumed to be restricted by household heat demands within 1 km grid cell. If the heat demands are lower than the supplies from systems, unused heat is not considered as the heat that can be recovered. In addition, household heat demands are presumed to be constant all year round for the evaluation of thermal recovery from methane fermentation systems in this paper; however, the fluctuation of seasonal heat demands should be taken into account for local-scale planning.

6. RESULTS & DISCUSSIONS

Overall CO_2 emission reductions are determined based on the energy recovery from energy consumed by STPs and household demands (please refer to Table 4).

- *CO_2 emission reduction from energy recovery of STPs*

Table 4 Std. heating value & CO_2 emission specific value

	Std. heating value[27]		CO_2 emission specific value[28]	
Heavy oil (type A)	39.1	MJ/l	71.6	gCO_2/MJ
Kerosene	36.7	MJ/l	68.5	gCO_2/MJ
Diesel	38.2	MJ/l	69.4	gCO_2/MJ
Gasoline	34.6	MJ/l	68.8	gCO_2/MJ
Town gas	41.1	MJ/m3	51.2	gCO_2/MJ
Propane gas	51.2	MJ/kg	58.6	gCO_2/MJ
Biogas	18.1	MJ/m3	-	-
Electricity	3.6	MJ/kwh	0.407	$kgCO_2/kWh$

The reduction amounts are calculated based on the assumption that energy converted from biogas substitutes present consumption patterns of electricity and other fossil fuels in the same proportions. Since some of the STPs are current equipped with anaerobic process and are using biogas as part of the energy source for operations, this portion of energy is accounted as energy requirement for running STPs but is not taken into account for CO_2 emission reductions that can be achieved in this research.

- *CO_2 emission reduction from energy recovery from household demands*

The amount of CO_2 emission that can be reduced from energy recovery from household fossil fuel demands is calculated by assuming the recovered energy substitutes household electricity and heat demands in the same ratio to the current situation in Kanto Region (please refer to Table 5).

Table 5 Household energy demand from fossil fuels

	Total Energy Consumption (TJ/yr) [27] (Kanto Region)	Proportional of fossil fuel consumption
Electricity	340,804	100%
Kerosene	102,987	29%
Town gas	105,707	25%
Propane gas	221,938	46%
TOTAL	**771,436**	

(1) Results of energy recovery and CO_2 emission reduction achieved in Tokyo Bay Region

In Case 1, depending on the organic collecting boundaries of 1 km and 5 km grid cell, 22,332 MWh of electricity with 86 TJ of heat, and 282,494 MWh of electricity with 1,354 TJ of heat, can be recovered yearly. On the other hand, in Case 2, recovery of 24,946 MWh of electricity with 99 TJ of heat, and 521,038 MWh of electricity with 1,963 TJ of heat, can be expected.

If comparing these values to the electricity and heat demands of household in Tokyo Bay Region, Case 1 achieves a recovery of 0.024% in electricity and 0.020% in heat demands for 1 km grid organic waste collecting boundary, and 0.30% in electricity and 0.31% in heat demands for 5 km grid collecting boundaries. In Case 2, 0.026% in electricity and 0.023% in heat demands, and 0.55% in electricity and 0.46% in heat demands, depending on organic waste collecting boundaries.

From the energy that can be reutilized, CO_2 emission reductions yearly in Case 1 is about 436-thousand and 800-thousand ton (about 83% increment), and 446- thousand and 960-thousand ton of CO_2 emission reductions (about 115% increment) in Case 2, depending on the organic waste collecting boundaries. In addition, about 400-thousand ton and 600-thousand ton of CO_2 emission reductions for 1 km and 5 km grid collecting boundaries respectively, are contributed by the energy saved in STP plants (please refer to Table 6 & Figure 13).

(2) Discussions

Table 6 Results of energy recovery & CO_2 emission

		Energy Recovery from Household Demands Yearly (Kanto)		% Energy Saving in Household Demand (Kanto)		Total CO_2 Emission Reduction (t-CO_2/year)
		Electricity (MWh)	Heat (TJ) (*1km-grid)	Electricity	Heat	
CASE 1	Sewage sludge + food waste (household, food distribution & manufacturing sectors)					
CASE 1	Organic waste collecting boundary (1km-grid)	22,332	86	0.024%	0.020%	436,000
CASE 1	Organic waste collecting boundary (5km-grid)	282,494	1,354	0.30%	0.31%	800,000
CASE 2	Sewage sludge + food waste (household, food distribution & manufacturing sectors) + agriculture waste + livestock excreta					
CASE 2	Organic waste collecting boundary (1km-grid)	24,946	99	0.026%	0.023%	446,000
CASE 2	Organic waste collecting boundary (5km-grid)	521, 038	1,963	0.55%	0.46%	960,000

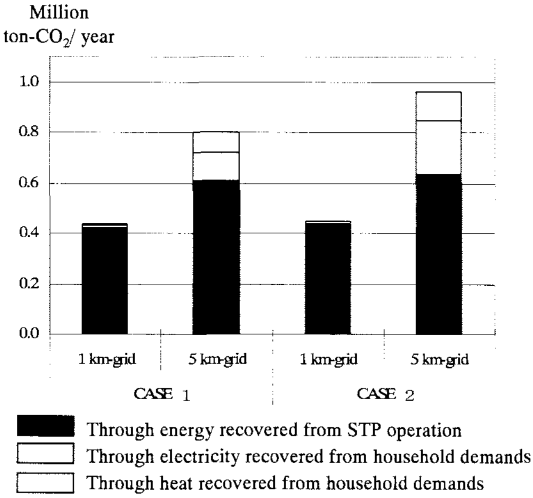

Figure 13 Detailed of CO_2 emission reduction from electricity and heat recovery

Few points are observed from the results as below:-

■ For 1 km grid collecting boundary in both cases, overall surplus energy is very limited due to low organic wastes quantity available around STPs. These imply that all types of human activities around STPs are limited. For 5 km grid collecting boundary significant increments in CO_2 emission reductions are observed due to the increase of organic waste inputs especially food waste from household which has a higher biogas production potential. In Case 2, significant input amount of agriculture waste available within 5 km grid also contributes to the additional CO_2 emission reduction.

■ Although 5 km grid collecting boundary in both cases achieve much better results in CO_2 emission reductions, thermal recovery is limited in both cases due to low household demands around some STPs. Overall about 33% and 31% of heat are wasted in the cases of 1 km grid collecting boundary; while in 5 km grid collecting boundary waste heat is increase from 17% in Case 1 to 35% in Case 2, due to increase of organic waste inputs from agriculture sector but relatively low household heat demands in rural area.

7. FUTURE EXTENSIONS

Since this paper is the first stage evaluation of our research, further extensions and improvements are necessary to establish a reliable model for macro type of regional planning.

(1) CO_2 emission through transportation

Because CO_2 emissions from the process of organic waste collections through transportation are not yet included, this factor will be incorporated into our calculations to evaluate the impact of CO_2 emission through transportation versus energy recovery from organic waste collected.

(2) Additional nitrogen loads to STPs

The amount and significance of additional nitrogen loads from integrated methane fermentation systems to STPs will be investigated to order to verify the effect upon STPs.

(3) Thermal recovery

Enormous heat is wasted due to low household heat demands around STPs. Thus, other public facilities are also aimed for the consideration of locations of system implementations. Different outcomes for large scale and centralized type versus small scale and dispersed type of implementation pattern are intended to be evaluated for optimal thermal recovery..

(4) Targeting energy saving on sewage waste-water treatment in STPs

Due to high energy consumptions for aerobic biological treatments in STPs, case designed for substituting sewage wastewater facility to methane fermentation system will also be evaluated.

The evaluation system is targeting on the issues of optimal organic waste collecting boundary and location and scale of integrated methane fermentation system which is closely related to thermal recovery. Integrative system implementation patterns with various policy options depending on regional properties and requirements (quality, quantity and demand-supply indicators[11]) are intended to be modeled for optimal energy recovery and CO_2 emission reduction.

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東京湾流域圏における混合メタン発酵を用いたCO_2削減効果の評価システムに関する研究

ウォン ルーイ ファン　藤田壮　鈴木陽太　岡寺智彦

本研究では地理情報システムを用いた東京湾流域圏の有機廃棄物の発生量と分布をデータベース化した上で、循環政策システムとしてメタン発酵システムを下水処理場に導入するケースについて、再利用エネルギーにより二酸化炭素（CO_2）の削減効果を評価する。ケース１では下水汚泥と家計、食品流通業、製造業から発生する食品残渣が対象となる。一方、ケース２については農村連携を考えた上でケース１の有機残渣とともに農業廃棄物と家畜排泄物も含んでいる。