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Scenario Evaluation of Biomass Utilization in Suburban Agriculture and Livestock Industry

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Abstract

In this research, we employed a scenario analysis to numerically evaluate alternative biomass utilization plan using *K* City as a case study area. The case study city, located in the vicinity of Tokyo metropolitan area, has been famous for its active engagement in pig farming. Our analyses aimed at fixed-quantity evaluation of the environmental impacts and economic balance for the four alternative biomass utilization scenarios. Scenario S1 introduced methane fermentation and gasification power plant. Scenario S2 substituted all the methane fermentation plants of S1 with composting plants. Scenario S3 and S4 introduced ethanol production plants to substitute gasification power generation plant introduced in S1 and S2. Using the Diagnosis Model for Biomass Resources Circulative Use (DMBRCU) (Morimoto *et al*., 2009 a, 2009 b), environmental impacts, fossil fuel consumption, greenhouse gases (GHGs) discharge and economic balance were evaluated for each scenario. Our analyses clarified that while all the scenarios could reduce the fossil fuel consumption, S4 showed increase in GHGs discharge. S1 and S3 both of which gave priority to energy (heat and power) production to material (compost) production seemed to be more effective to cope with global warming prevention through the reduction of fossil fuel consumption. Our results also pointed out the importance of designing "Local Circulation Area", including municipalities located around *K* City, to achieve effective utilization of biomass energy and products produced while reducing the risk of over nitrogen resulted from excessive use of compost and/or liquefied fertilizer.

Keywords: Biomass, Scenario Evaluation, Environmental Impact, Economic Impact

1. Introduction

The government of Japan enacted "Fundamental Act for Establishing a Sound Material-Cycle Society" in 2001 to promote a recycling-oriented society which establish a general framework of waste management and recycling. This was followed by a series of amendment and formulation of waste management and recycling legislations. In 2002, the government made a cabinet decision on "Biomass Nippon Strategy" to promote the use of biomass resources and wastes. The strategy, as an inter-ministerial decision, specified roles of relevant ministries. One of the most important policies put in place in response to the strategy is the *Biomass Town* program administered by the Ministry of

Agriculture, Forestry and Fisheries. In this program, municipal governments are able to formulate a vision of biomass town which describe current situation of biomass utilization as well as strategies to promote the utilization of biomass utilization. As of February, 2008, seventy municipalities have established their own vision on biomass town.

In planning the biomass utilization, first, the government needs to take into account the type and amount of biomass resources available in target areas to draw alternative plans and then, evaluate the environmental and economic impacts to be resulted from alternative plans so that we can clarify both advantages and disadvantages of each plan. In this study, following this idea, we employed scenario analysis to numerically evaluate alternative biomass utilization plans using *K* City as a case study area (Fig. 1). The case study city, located in the vicinity of Tokyo metropolitan area, has been famous for its active engagement in pig farming. Thus, our analyses aimed at fixed-quantity evaluation of the environmental impacts and economic balance for the four alternative biomass utilization scenarios.

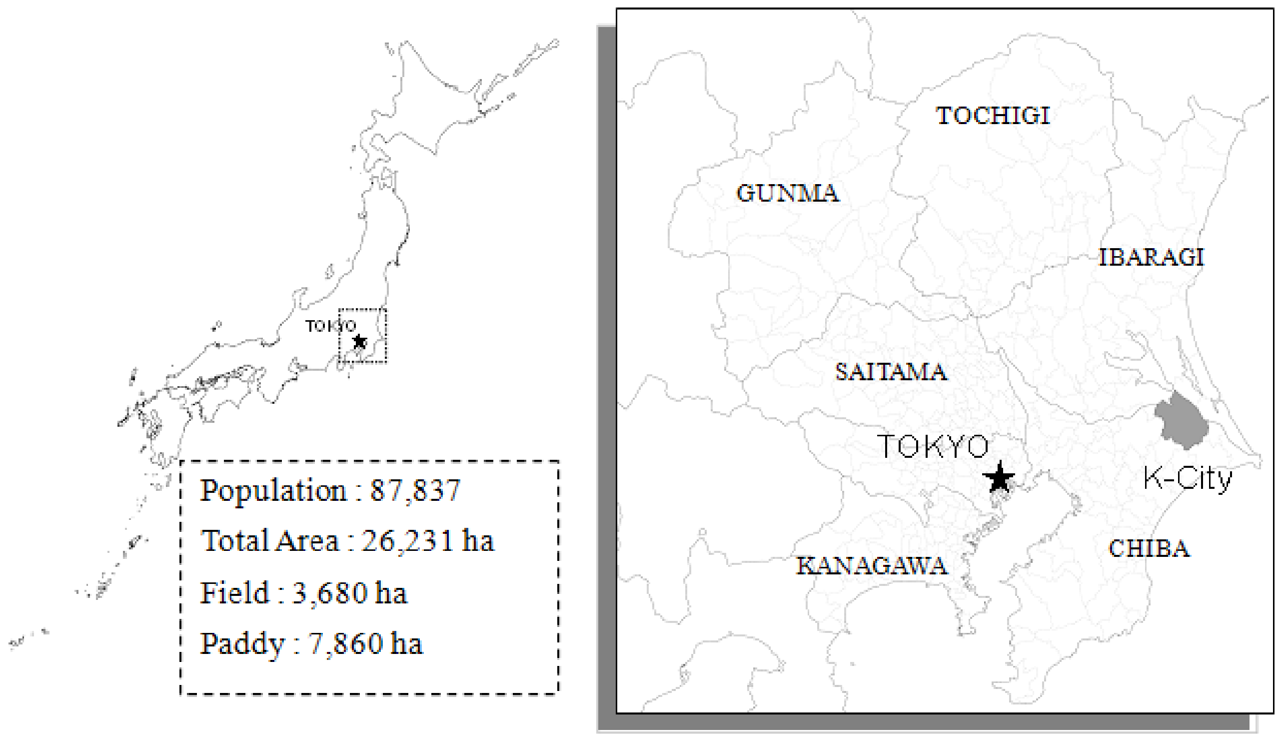

Fig. 1.Case study area

2. Methodology

We employed scenario analysis to compare advantages and disadvantages of alternative biomass utilization scenarios. The scenarios in this study were describes as combinations of type & amount of biomass resources and conversion technologies.

2.1. Type & Amount of Biomass Resources

With its large population, about 90 thousand, and active engagement of farming including pig raising, there exist abundant kitchen garbage, manure and rice straw in the case study area, which play a central role in drawing biomass utilization scenarios. Other biomass taken in to account in our scenarios include rice husk and wood and resource crops. In sum, these biomass resources roughly fell into three groups: biomass wastes such as kitchen garbage and manure, unused biomass such as rice straw and husk and resource crops such as fodder rice and coleseed.

2.2. Conversion Technologies

For the conversion technologies for utilizing biomass, the following options were taken into account in our analysis: a) composting, and methane fermentation for kitchen garbage and manure, b) gasification power generation by used papers, rice husk, rice straw and woody biomasses, c) BDF production from waste cooking oil and energy (ethanol, BDF) production from resource crops such as fodder crop rice and coleseed.

2.3. Scenarios and System Boundary

Considering the type & amount of biomass resources and conversion technologies, four alternative biomass utilization scenarios were drawn as follows Figure two shows available biomass resources in *K* City of which 82 % is dominated by livestock manure and agricultural by-products. In formulating scenarios, firstly, we design recycling strategy for these biomass resources. Since the recycling technology suitable for kitchen garbage is same as the one for livestock manure.

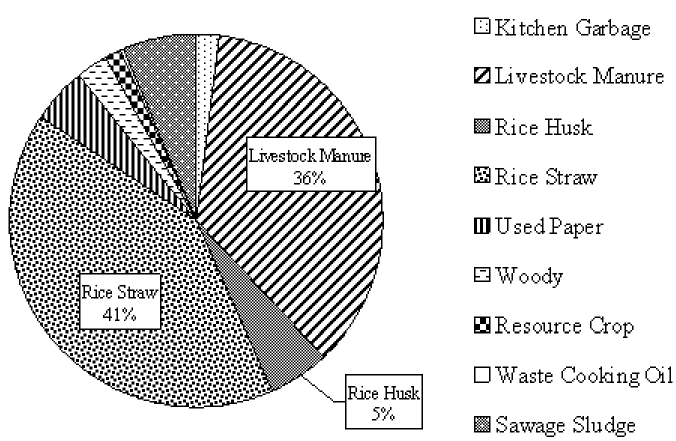

Fig. 2. Utilizable Biomass in *K* City

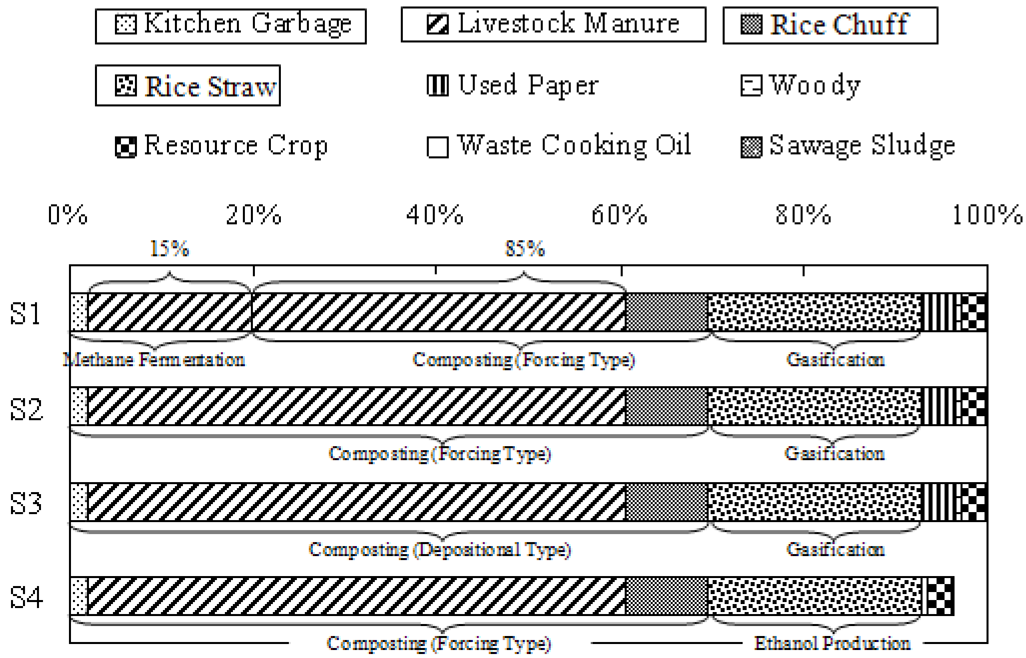

Fig. 3. Utilization of Main Biomass about each Scenario

In Scenario 1 (S1), 15% of livestock manure and kitchen garbage are brought to methane fermentation plant, and the rest (85%) is composted. Forcing fermentation process which requires energy input is used for composting. All the rice husks is utilized in composting process. Rice straw is utilized in gasification power generation. In Scenario 2 (S2), all the livestock manure and kitchen garbage are composted while rice husk and rice straw are utilized as same as S1. Scenario 3 (S3) assumes that all of recycling technique are same as S2. However, for composting, depositional fermentation process is employed instead of forced fermentation applied in S1 and S2. In Scenario 4 (S4), recycling of livestock manure and rice husk is as same as S2 while rice straw is utilized for ethanol production.

Table 1 The Biomass Utilization Method for Others

Biomass	Used Paper	Woody	Waste Cooking Oil	Resource Crops
S1, S2, S3	Gasification	Gasification	BDF Production	BDF and Ethanol Production
S4	-	Pellet Production		

2.4. Evaluation Model

To analyze the scenarios, we applied Diagnosis Model for Biomass Resources Circulative Use (DMBRCU), which we had been developed by authors. In depth description of the model development is available in Morimoto *et al*. (2009a, 2009b). To be brief, based on life cycle approach, the model enables us to evaluate environmental impacts, fossil fuel consumption, greenhouse gases (GHGs) discharge and economic balance. It also evaluates using the evaluation index which Doi *et al*. (2009) proposes.

We set the different system boundary for three biomass groups to evaluate the economical balance and environmental impacts such as GHGs discharge and energy consumption. For biomass wastes, procurement, conversion and product transportation processes were taken into account in the analysis. For unused biomass, collection processes were also considered along with procurement, conversion and product transportation. For resource crops, cultivation processes were evaluated in addition to collection, procurement, conversion and transportation processes. All of the converted material such as compost and liquefied fertilizer and energy such as electric power and heat were assumed to be sold.

2.5. Evaluation Method

To identify the relative location of the case study area in whole of country, we calculated quartile point of each criteria for 70 municipalities, which is used to set up the rank ranging from A (superior) to D (inferior) as shown in Table 2. Then, rank A, B, C and D are scored as 4, 3, 2, and 1. Finally, we calculated simple sum score, which we named Synthetic Evaluation Point (SEP).

Table 2. The Range of the Evaluation Level Classified by Evaluation Criteria for Scenario Evaluation (unit: /year)

	Rank			
Item	A	B	C	D
Disposal (kg-C/Capita)	~ 219	219 ~ 397	397 ~ 613	613 ~
Cyclic Utilization of Nitrogen (t-N/ha)	~ 0.1	0.1 ~ 0.2	0.2 ~ 0.5	0.5 ~
Economic Balance (1000 JPY/Capita)	-1.9 ~	-6.4 ~ -1.9	-20.4 ~ -6.4	~ -20.4
GHGs Discharge (kg-CO_2eq./ Capita)	~ -47.4	-47.4 ~ -15.1	-15.1 ~ 19.5	19.5 ~
Carbon Efficiency (%)	75.4 ~	64.3 ~ 75.4	43.7 ~ 64.3	~ 43.7
Carbon Utilization (kg-C/Capita)	234 ~	92 ~ 234	54 ~ 92	~ 54
Fossil Fuel Consumption (L-Heavy Oil/Capita)	~ 57.4	-57.4 ~ -15.3	-15.3 ~ -0.5	-0.5 ~

3. Result and Consideration

Our analysis identified that all the four scenario could reduce GHGs between 616(S4) and 14,493 (S1) t-CO_2eq. per year. Furthermore, the consumption of heavy fuel oil could be reduced between 2,018 (S4) and 11,276(S3) *kl*-heavy oil per year. Economical efficiency is between 6.7 (S3) and -35.4 (S4) thousand JPY per capita.

3.1. Relative location of the case study area among 70 municipals

Figure 3 show the result of evaluation. Our analysis identified that the amount of biomass wastes, carbon utilization ratio and the amount of nitrogen circulation of the case study area are below the national average. The amount of carbon utilization, energy consumption reduction and GHGs discharge reduction were more than the average while economic efficiency became below the average except for S3.

3.2. Scenario

Among four scenarios, the differences were identified in energy consumption reduction, GHGs discharge reduction and improved economical efficiency while the amount of carbon utilization and nitrogen circulation of the four scenarios were at the same level. As a result, the synthetic evaluation score of S3 was the highest, which was followed by S1and S2. S4 was the worst case in our analysis. S3 showed the best economic performance because S3 continued to employ conventional composting facility without introducing a new conversion technology which often brings about economic burden. However, conventional composting facility has been infamous for its strong odor and product quality, which may prevent sustainable use of biomass resources. If government, either national or local or both, subsidize operating costs (initial or running cost), economic efficiency of S1 and S2 would improve to rival that of S3. Since S4 utilized the least amount of biomass resources, this scenario resulted in the lower score of energy consumption and of GHGs discharge reduction compared with the other scenarios. However, if the use of biomass ethanol would become more popular for heat and power generation, this scenario might become an effective alternative because the case study city could work as one of supply centers for Tokyo metropolitan area.

In reality, utilizing all the converted biomass resources, especially for nitrogen, within *K* City seems to be difficult since the maximum input of nitrogen fertilizer for *K* City was estimated to be 608 t-N / year based on the prefectural standard of nitrogen application (Chiba Prefecture defines and cultivation area based on Census of Agriculture and Forestry, 2005). To be precise, the amount of compost and liquefied fertilizer production were between 1,227 (S1) and 1,289 (S4) t-N, which were more than twice as much as the prefectural standard. As such, in order for *K* City to fully utilize biomass resources, cooperation with neighboring municipalities in biomass utilization could be an effective option.

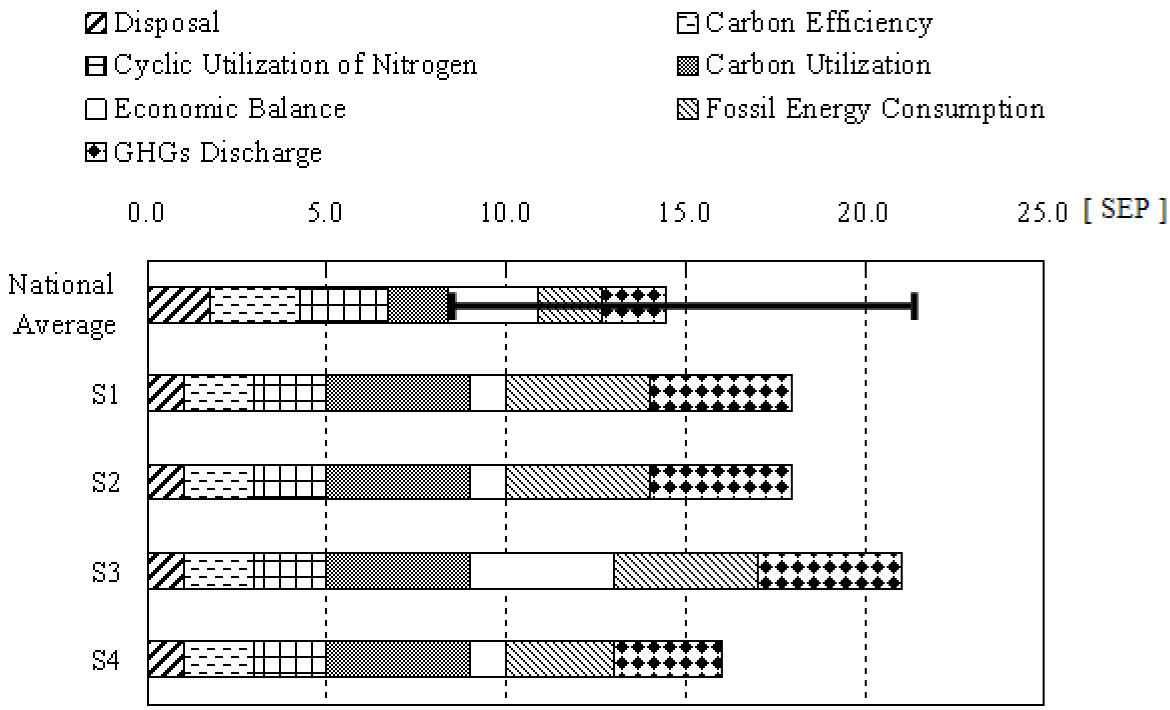

Fig. 3 Integrated Assessment Result of Biomass Use

4. Conclusion

In this study, we performed scenario analysis of the biomass utilization using *K* City as case study area. Our analysis identified that all the four scenarios could successfully reduce GHGs discharge and fossil energy consumption. Among them, the best scenario was S3 in synthetic evaluation. However, in order to cope with issues of global warming prevention and/or energy depletion, the scenario of S1 or P4 with energy production might be more effective because these scenarios emphasize the production of biomass-energy. Our analysis also identified the scale issue of biomass utilization. In carrying out material recycling only in the area with abundant livestock like our case study area, utilizing all the converted materials within the same area seems to be impossible considering the nitrogen application standard. Cooperation with neighboring areas would solve such issues as it could expand possible areas for nitrogen application. Thus, we propose that the spatial extent of resource circulation would be also an important aspect in planning biomass utilization as it often defines the amount of biomass resource consumption. Such idea is recently known as "local circulation region" (Environment Ministry, White Paper on Material-Cycle Society, 2009).

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