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Regional Diagnosis of Biomass Use in Suburban Village in Southern Vietnam

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To establish a sustainable regional biomass use system, clarifying the present condition in the objective area and proposing a proper scenario to improve the present conditions are important. In this study, one suburban village where rice cultivation and livestock industries are popular in Southern Vietnam was selected as the objective area. Literature review, interviews at the site and field surveys were conducted to analyze material flow in agricultural production and excreta treatment of livestock. As a result, it was clarified that surface water quality at some points in the canals, rivers and wells of the village did not meet the national standard, and contributions of discharges of untreated livestock excreta to total nitrogen loads to lower water bodies were large (43% in total). From another aspect, some rice straw was burned without any effective use at the paddy fields. For this situation, two scenarios were proposed and designed as “Plan model 1” and “Plan model 2”. The one is to increase biogas digesters in the village for treatment of untreated livestock excreta, decrease washing water rate poured into biogas digesters and use slurry from the biogas digester (hereafter, slurry) at paddy and non-paddy fields as a fertilizer. Another is to use unused rice straw for producing bio-ethanol. By these scenarios, the possibility was shown that approximately 327,000 Nm³/year of biogas and more than 240 kL/year (= 190 t/y) of bio-ethanol can be produced in objective village, 39% of nitrogen load to water bodies and 95% of application rate of chemical fertilizer to agricultural field could be decreased, and greenhouse gas emission rate could be decreased if bio-ethanol is substituted for fossil fuel.

持続可能な地域バイオマス利用システムの確立のためには、対象地域の現状を把握し現状に対する適切なシナリオを提案することが重要である。本研究では、ベトナム南部の稲作と畜産が盛んな都市近郊農村を対象とし、農業生産と家畜ふん尿処理における物質フローを分析するため、文献調査や現地での聞き取り調査および野外調査を行った。調査および分析の結果、村内の水路や河川、井戸のうち、国の水質基準を満たしていないところが数か所あること、未処理の家畜ふん尿の垂れ流しが下流水域への窒素負荷に寄与する割合が大きいこと（下流水域への窒素負荷全体の43%）等の問題点が明らかにされた。また、水田では一部の稲わらが有効利用されずに燃やされていることが明らかにされた。この現状に対し、2つのバイオマス有効利用シナリオを提案した。1つ目は、現在未処理の家畜ふん尿処理のために村内のバイオガスダイジェスター数を増加させ、バイオガスダイジェスターへの畜舎の洗浄水の混入量を削減し、バイオガスダイジェスターから発生する消化液を水田や畑地で肥料として利用するというシナリオである。2つ目は、現在未利用の稲わらをバイオエタノール生産の原料にするというシナリオである。分析の結果、提案するシナリオにより、対象地域においておよそ327,000 Nm³/yearのバイオガスと240 kL/y以上のバイオエタノールの生産が可能であること、および水域への窒素負荷と農地における化学肥料の使用量がそれぞれ39%および95%削減可能であること、さらにはバイオエタノールが化石燃料に代替することによる温室効果ガス削減の可能性を示すことができた。

Key Words

Digested slurry, Resource circulation, Biogas digester, Material flow

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1. Introduction

Vietnam and Japan have strong relationships in agriculture, society and economy¹⁾. Today in Vietnam, demands for electricity and primary energy are increasing with rapid industrialization and economic growth. It is forecasted that annual energy demands will increase approximately 12.1% from 2010 to 2020, accompanied with yearly decreases in fossil fuel sources²⁾, and Vietnam becoming a net importer of energy. Under these circumstances, agriculture is still major industry. Vietnam is known as the world's 2nd largest exporter of rice³⁾, and 70% of the population is living in rural area²⁾. By-products such as rice husk and rice straw are generated in rice cultivation, and these have potential to be energy such as bio-ethanol through some effective process. From another aspect, the livestock industry has been rapidly increasing with greater demands for meat products, and air pollution such as odor and pollution of aquifers and surface water caused by improper treatment of livestock excreta are becoming very serious^{4)~7)}. These wastes also have potential as an energy source if proper treatment is conducted.

For these circumstances in Vietnam, effective use of unused biomass for energy production should be countermeasures for both the possible energy shortage in the future and environmental pollutions stated above. Therefore, we suggest to establish a sustainable regional biomass use system. In the system, energy used in a region is basically produced from the regional biomass which is abundant in the region.

Our objective in this study was to propose sustainable regional biomass use scenarios in a suburban village in Southern Vietnam by "regional diagnosis", a method to clearly clarify the present conditions in the objective area by constructing a material flow model. Each value used in the model is based on existing statistical data, obtained by hearing surveys or direct measurements at the sites and a literature review. We conducted the regional diagnosis of biomass use in a suburban village in Southern Vietnam where rice cultivation and livestock industries are popular⁸⁾. The study clarified that the contributions of discharged untreated livestock excreta as sources of nitrogen loads to lower water bodies were large, and a new biomass use scenario as a countermeasure for it was proposed as follows; using all untreated pig and milk cow excreta as feedstock for biogas digesters, using the slurry from biogas digesters in agricultural fields as fertilizer. Then, the possibility of a reduction of 43% of nitrogen load to lower water bodies and increase of 8 times of biogas production compared to the present conditions was shown by introducing the new

scenario. We had continued the survey such as household interviews on biomass use and rice cultivation test using the slurry from the biogas digester at the paddy field on the site, and have collected data from a previous study⁸⁾. In this study, we revised the present material flow model of biomass use in the village based on the latest data, and proposed two new biomass use models based on the following scenarios; 1) Increasing biogas digesters in the village to treat all untreated pig excreta and milk cow excreta, decreasing the rate of washing water into biogas digesters, and using all slurry in paddy and non-paddy fields. 2) Using the rice straw which is now not used effectively to produce bio-ethanol. Then, the effect of the new regional biomass use scenarios proposed in this study for regional energy production and the environment was clarified by comparing the present model and plan models.

2. Method

2.1 Objective village

Objective village for this study was Thai My Village in Cu Chi District, Ho Chi Minh City, located about 43 km north-west from the center of Ho Chi Minh City. In this village, rice cultivation and livestock industries are popular. Annual rainfall is approximately 1,880 mm, and there are two seasons, a dry season and a rainy season. Household-scale methane fermentation systems for livestock excreta, so called "biogas digesters" has become popular in this village promoted by the government-led program⁹⁾. There are 111 households that have biogas digesters with capacities of $7.8 \pm 1.2 \text{ m}^3$ in fermentation tank volume. Information and data collected by the surveys are shown in Table 1.

2.2 Procedure of the regional diagnosis

Regional diagnosis was conducted by the following procedures.

At first, data needed for analysis of the present conditions of biomass use for the objective area were collected by interviews, field surveys and literature reviews. Content and method of data collection is summarized in Table 1. Second, the present conditions of biomass use are represented as the "present" model. The model is composed of a "compartment (box)" that represents space to generate, convert or use biomass, and "arrow" that represents material flow. The compartments involve livestock farming, agricultural fields, biogas digesters, and composting facilities, etc. We had to substitute some data for Japanese ones though on-site or Vietnamese original data should be used for the regional diagnosis. Most data related to non-paddy fields were substituted by Japanese ones. However, the regional diagnosis in this paper is focused on material

Table 1 Data collected for regional diagnosis

Item	Data [(Data source)]
a. Basic information	
(a) Land use and the area	
Total area of the village	2,415 ha [(1)]
Road	113 ha [(1)]
River and Canal area	123 ha [(1)]
Residential area	159 ha [(1)]
(b) Population	
Population	10,849 people [(1)]
Number of households	2,873 households [(1)]
Number of farmer households	967 households [(1)]
Agricultural workers	2,224 people [(1)]
(c) Variety and usage of energy at home	
Fuel variety	Electricity, Wood, Biogas, Rice straw and husk [(1)]
Usage of fuel	Electrical equipment, Lighting, TV, Radio, Stove burner, Cooking [(1)]
(d) Conditions of sources for drinking water	
Water well in house (Depth: 4-50m), Tank for drinking water [(1)]	
(e) Environmental problems	
Discharge of large quantity of untreated pig excreta [(1)]	
b. Agriculture information	
(a) Main crop situation, annual planted area	
Rice	544 ha, 2 or 3 crops in a year according to the economic situation or field conditions [(2)]
Corn and peanuts	200 ha [(2)]
Vegetables	75 ha [(2)]
Fruits	146 ha [(2)]
(b) Agricultural machine	
Machine types and numbers in the village	Combine; 2 equipment Tractor; 7-8 equipment Rice mill; 4 equipment Tilling machine, Water pump [(2)]
Fuel types for machine	Diesel oil (for large machine), Gasoline (for small machine) [(2)]
c. Information about rice cultivation	
(a) Variety and application rate of fertilizer	Mixed fertilizer of NPK, Urea, Phosphorus, Potassium, etc. 500-900kg/ha/crop [(3)]
(b) Method for water management	By portable pump owned by farmer through canals nearby the field [(4)]
(c) Water quality of canal and river	Shown in Table 2 [(5)]
(d) Amount of irrigation water	10,286.28 t/ha/y [(App.1 No.7)]
(e) Annual precipitation	18,818 t/ha/y [(App.1 No.4)]
(f) Ammonia volatilization	0.0017 t/ha/crop [(App.1 No.21)]
(g) Denitrification	0.03 t/ha/crop [(App.1 No.19)]
(h) Nitrogen fixation	0.0178 t/ha/crop [(App.1 No.13)]
(i) Carbon dioxide emission	2,952 t/y [(App.1 No.26)]
(j) Percolation	202 mm/ha/crop [(App.1 No.22)]
(k) Methane gas emissions	160 kg/ha/y [(App.1 No.24)]
(l) Yield and by-products	

Yield	Winter-spring crop; 5.0-6.0 t/ha/crop [(1), (6)]
	Spring-summer crop; 3.0-4.0 t/ha/crop [(1), (6)]
	Sumer-autumn crop; 3.0 t/ha/crop [(1)]
Average yield	4.0 t/ha/crop (2,176 t/y) [(1), (6)]
*“Yield” indicates 15% moisture of unhulled rice.	
*Rice is harvested 10-20 cm above the ground, so rice straw is divided into upper part and lower part.	
Rice husk	434 t/y; Used for making compost [(1), (6)]
Rice bran	191 t/y; Used for feed for livestock [(1), (6)]
Rice straw (Upper part)	1,618 t/y; Not used, burned in the field
	405 t/y; Shipment to outside 405 t/y; Used for feed for livestock In total; 2,428 t/y [(1), (6)]
Rice straw (lower part)	582 t/y; Remained, burned in the field [(1), (6)]
d. Information about cultivation except for rice	
(a) Variety and application rate of fertilizer	
Chemical fertilizer	Corn; 3,500kg/ha/y Vegetables; 2,560kg/ha/y Fruits; 4,000 kg/ha/y [App.2 No.3, 9, 12]
Compost	25 t/ha/y [App.2 No.5]
(b) Nitrogen fixation	0.11 t/ha/y [App.2 No.29]
(c) Carbon dioxide emissions	3,859 t/y [App.2 No.32]
(d) Nitrogen loss by emission	0.018 t/ha/y [App.2 No.31]
(e) Percolation	2,377,969 t/y [App.2 No.35]
(f) Yield	Corn; 7.5 t/ha/y Vegetables; 62.95 t/ha/y Fruit; 0.824 t/ha/y [App.2 No.14, 17, 20]
e. Information about livestock	
(a) Kinds and numbers	
Beef cow	1,659 heads [(7)]
Milk cow	61 heads [(7)]
Buffalo	400 heads [(7)]
Pig	11,000 heads [(7)]
Poultry	8,000 heads [(7)]
(b) Method of livestock raising, variety of feed	
Beef cow and buffalo	Raised outside in daytime and in cattle shed at night [(8)]
Milk cow and pig	Raised in cattle shed [(8)]
Feed	Bran, grass, etc. [(8)]
(c) Generation rate of livestock excreta and its contents	
Pig	Feces; 0.73 t/head/y (C; 18.68%, N; 0.83%)
	Urine; 0.49 t/head/y (C; 0%, N; 32.5%) [App.3 No.2-6]
Beef	Feces; 8.22 t/head/y (C; 15.75%, N; 0.7%)
	Urine; 4.56 t/head/y (C; 0%, N; 27.1%) [App.3 No.8-12]

Milk cow	Feces; 8.22 t/head/y (C; 8.55%, N; 0.38%) Urine; 4.56 t/head/y (C; 0%, N; 27.1%) [App.3 No.14-18]
Buffalo	Feces; 8.22 t/head/y (C; 6.98%, N; 0.31%) Urine; 4.56 t/head/y (C; 0%, N; 27.1%) [App.3 No.24-28]
(d) Flow of livestock excreta	
Pig excreta	Approximately 10%; Used as feedstock for biogas digester 10 t/week of feces shipped outside the village as feedstock of compost Rest is discharged to lower water bodies [(8)]
Milk cow excreta	Approximately 10%; Used as feedstock for biogas digester Rest is discharged to lower water bodies [(8)]
Beef excreta	Half of feces sold outside the village Another half of feces are used as feedstock for composting at composting facility Rest is discharged to the lower water bodies [(8)]
Buffalo	Similar to beef cow excreta [(8)]
(e) Information about biogas digester	
Number in the village	111 equipment [(8)]
Capacity	$7.8 \pm 1.2 \text{ m}^3$ in the village. [(8)]
Feedstock	Pig excreta and milk cow excreta [(8)]
Biogas generation rate	$746.7 \text{ (Nm}^3\text{/(t-Carbon of feedstock biomass))}$ [(8), (9)]
Usage of biogas	Mainly cooking in farmer households [(8)]
Treatment of slurry	Partially used for trees in the backyard, adjacent crop field of farmer's house or fish pond, and mostly discharged to canals and rivers with or without passing through soil [(8)]

(Abbreviation)

HCMUT: Ho Chi Minh City University of Technology

DOST-HCM: Department of Science and Technology

DARD-HCM: Department of Agriculture and Rural Development

VPC: Thai My Village People Committee

Cu Chi PC: People Committee of Cu Chi

App.; Appendix

(1) Interviews of VPC, DOST, Cu Chi PC and Villagers

(2) Interviews of VPC, DOST, Cu Chi PC, Villagers and DARD

(3) Interviews of VPC, Villagers

(4) Interviews of VPC, Villagers and DOST

(5) Sampling surveys conducted in Thai My Village

(6) Field survey at test field in Thai My Village

(7) Interviews of VPC and DARD

(8) Interviews of Villagers

(9) Calculation based on data by Interviews of Villagers

flow around paddy field compartment in “Plan model 1” and “Plan model 2”. Therefore, most of all conclusions in this study reflects Vietnamese on-site situation.

Components of materials for analysis in this study are raw weight, water content, carbon content and nitrogen content of feedstock biomass and products. Each value in the model was calculated by multiplying the specific unit of each parameter by its abundance. Specific unit is based on the surveys or literature and the data sources and detailed calculations are shown in the appendix of this paper. Third, improvable points, that is, the points which could contribute to the increase of energy production from regional biomass in the present conditions are focused, and some scenarios that would be improvements in terms of sustainable regional biomass use were proposed and designed as the “plan” models.

Interviews were conducted from 11 to 29 January 2010 and 27 October 2010. Interviewees were farmers and public administrations such as DOST (Peoples Committee of Ho Chi Minh City, Vietnam Department of Science and Technology), DARD (Department of Agriculture and Rural Development of Ho Chi Minh City), People committee of Cu Chi district, People committee of Thai My Village, the objective village in this study.

Field surveys of water quality in the canal, river and household wells (depth of borehole; 30-60 m) was conducted for seven times in the objective village from 2010 to 2012. Ten sampling points and three sampling points were selected for surface water and ground water, respectively, as shown in Fig. 1. Field surveys at rice cultivation test field in the objective village were conducted from 6 December

Fig. 1 Sampling points of surface water and ground water in Thai My Village (*about signs in above map, “SW” indicates sampling points of surface water, and “GW” indicates sampling points of ground water (depth; 30-60 m))

2011 to 24 March 2012, and from 11 May to 17 August 2012 to obtain data on conventional cultivation with chemical fertilizers. In these tests, rice cultivation was conducted by the contracted farmer with our study team in 1 hectare of a paddy field. Data and information such as application rate of fertilizers and agrochemicals, the volume of irrigation and drainage water, yield and the amount of by-products were obtained from record of working diary and direct measurements at the site. In the same test field, rice cultivation tests using slurry from biogas digesters as substitute for chemical fertilizers was conducted under the comparison with the cultivation by chemical fertilizer by setting 8 m² of experimental plots^{10) 11)} from 11 December 2012 to 13 March 2013, and 200 m² of experimental plots from 14 December 2013 to 26 March 2014^{12) 13)}. In these tests, data on application rate of fertilizer and

agrochemicals, yield and yield components were collected by measurements at the site.

3. Results and Discussion

3.1 Estimation of present conditions of biomass use

Fig. 2 is the regional diagnosis model of present conditions on biomass use in Thai My Village. The ratio of slurry from biogas digesters to ponds as feed for fishes was very little in the village, so, the description of it in the model is omitted. Analysis of the model, followings were pointed out:

1) Out of the total livestock excreta of 40,861 t/year, 13,683 t/y brought outside the village as feedstock for compost, 8,458 t/y used in a village as feedstock for compost, 2,102 t/y used as feedstock for biogas digesters and 16,618 t/y, that is, approximately 41% of the total discharged to the lower

Fig. 2 Present condition of Thai My Village

water bodies without any treatment.

2) Nitrogen effluent load to water bodies came from untreated livestock excreta, untreated slurry from biogas digesters, discharged from agricultural fields and so on, counting 131.6 t/year in total. The load from untreated livestock excreta accounted for approximately 43% that would cause water pollution.

3) Number of biogas digesters introduced were 111 units so far accounting for 5% coverage, namely approximately 2,102 t/year in generated livestock excreta. In many cases, more than 5 times the volume of washing water of cattle shed of livestock excreta is poured into biogas digesters. Usage of digested slurry as liquid fertilizer is limited.

4) Actually, farmers with biogas digesters discharge higher ratio of nitrogen to water bodies than farmers without biogas digesters in present condition. For example, total nitrogen output from biogas digesters (which could be assumed as farmers with biogas digester) is 8.4 t/y, and within this, discharge rate to water bodies is 7.6 t/y, that is, approximately 90% of total. Whereas, about livestock excreta except for input to biogas digesters (which could be assumed as farmers without biogas digesters), total output is 88.2 t/y as the total of the flow to outside village, composting facility and water bodies, within this, discharge rate to water bodies is 57.0 t/y, that is, approximately 65% of total. This result supports the result shown by Vu *et al.*⁵⁾ who studied flows of nitrogen, potassium and phosphorus in pig farmers with and without biogas digester in Vietnam, and showed that pig farmers with biogas digesters discharge higher ratio of nitrogen than pig farmers without biogas digesters. They assumed the reason is that slurry from biogas digesters are high diluted by washing water of cattle shed (in their case, the ratio of manure to water is 1:11 as the maximum), large volume and low nitrogen concentration of slurry makes difficult for farmers to use it in agricultural fields. In our study, the situation was similar. The main reasons of without use of slurry at agricultural fields were the difficulty of transportation and lack of knowledge of application method of high-diluted slurry to the field. Therefore, by decreasing the water content of slurry and developing the method of transportation and application, the use of slurry in agricultural fields could be promoted and discharged rate of nitrogen to water bodies would be decreased to lower rate than it of farmers without biogas digesters.

5) Water quality parameters such as COD, BOD₅, NO₃⁻, NH₄⁺ in the surface water and ground water at some sampling points, especially, near the livestock farms in the village were over the standard value in Vietnam^{14) 15)} as shown in Tables 2 and 3.

Table 2 Surface water quality of river and canals in Thai My Village

	COD mg/L	BOD ₅ mg/L	NH ₄ ⁺ mg/L	NO ₃ ⁻ mg/L	TN mg/L
SW1*	89	19.7	1.5	20.1	9.0
SW2	72	18.6	1.1	1.5	6.5
SW3	138	19.1	1.6	0.9	3.0
SW4	98	28.9	3.4	1.2	7.8
SW5	84	21.1	1.2	0.4	3.2
SW6	75	20.0	3.8	1.5	9.0
SW7	125	17.1	1.5	3.3	5.6
SW8	84	27.9	3.1	4.3	8.6
SW9	254	74.0	7.4	2.3	18.5
SW10	14	5.4	0.2	0.2	0.7
QVCN08**	≤30	≤15.0	≤0.5	≤10.0	-

*SW1-SW10 are the sampling points as shown in Fig.1 Each value is the average of all sampling surveys and **"QVCN08" is standard for surface water in Vietnam, "QVCN08: 2008/BTNMT"

Table 3 Ground water quality in Thai My Village

	pH	TOC mg/L	NH ₄ ⁺ mg/L	NO ₃ ⁻ mg/L	TN mg/L
GW1*	6.4	2.2	3.1	2.7	7.1
GW2	5.8	4.9	0.2	0.3	0.5
GW3	5.4	0.9	0.1	0.5	0.8
QVCN09**	5.5-8.5	-	≤0.1	-	-

*GW1-GW3 are the sampling points as shown in Fig. 1

Each value is the average of all sampling surveys and **"QVCN09" is standard for ground water in Vietnam, "QVCN09: 2008/BTNMT"

6) Amounts of rice straw, rice husk and rice bran produced in the field is approximately 3,010 t/y, 434 t/y and 191 t/y, respectively. Rice straw of 3,010 t/year consists of 2,428 t/year of upper part and 582 t/year of lower part. The upper part is harvested above 10-20 cm from the ground, and lower part is remained in the field. In Fig. 2, rice husk, rice bran and rice straw is shown as flow from "Paddy fields" to "By product". Within "By-product", 405 t/year transported outside the village, 595 t/year used as feed for livestock and 434 t/year used as feedstock for compost inside the village. Whereas, 1,618 t/year of upper part of rice straw, which is larger than "By product" was not used effectively and burned in the fields with 582 t/y of lower part of rice straw within a few weeks after harvesting.

3.2 Design of the plan model 1; Use of slurry from biogas digester in paddy fields

Focusing to decrease water pollution in canals and rivers, and increase energy production from biomass, the scenario for the plan model was designed as follows:

1) All unused pig and milk cow excreta considered as feedstock for biogas digesters. By increasing the number of

biogas digesters, excreta from 10,288 heads of pig and 61 heads of milk cow becomes the target.

2) Decreasing the water content poured into a biogas digester from 5 times volume of livestock excreta to the same volume as livestock excreta which is the recommended ratio by operation manuals for house-hold scale biogas digesters¹⁶⁾. Though Vu *et al.*⁵⁾ recommended the method to separate the water from the slurry by rice straw filtration system¹⁷⁾, the system needed to improve on nutrients' removal efficiency.

3) Produce digested slurry from biogas digester used at non-paddy fields with the same application rate as "present conditions", and all the rest used at paddy fields as fertilizer.

4) Total nitrogen in the slurry considered for replacement for chemical nitrogen fertilizer based on the results of rice cultivation tests using slurry at the site.

Based on the above assumed scenario, material flow in a village was calculated as shown in Fig. 3. Highlighted results are arranged in Tables 4-6. Effluent nitrogen load decreased to 79.7 t/year from 131.6 t/year, equivalent to

Table 4 Changes in nitrogen load to lower water bodies from each source

Source of nitrogen load	Present	Plan*
	Nitrogen load t/year	
Livestock excreta	57.0	12.7
Leaching from non-paddy	50.8	50.8
Leaching from paddy fields	12.1	12.1
Surface drainage from paddy	4.1	4.1
Digested slurry	7.6	0.0
Total	131.6	79.7

*Plan indicates Plan model 1

Table 5 Changes in chemical fertilizer use rate at paddy fields

Present		Plan model 1	
Weight	Nitrogen	Weight	Nitrogen
t/year		t/year	
457	54.4	21	2.5

Fig. 3 "Plan model 1" based on the scenario of increasing biogas digesters and using the slurry from them in the paddy fields

Table 6 Change in biogas generation rate from biogas digesters

Feedstock of biogas digester	Present	Plan model 1
	Biogas generation rate N m ³ /year	
Pig excreta	51,394	320,452
Milk cow excreta	731	6,370
Total	52,125	326,822

39% reduction. Application rate of nitrogen fertilizer for rice cultivation decreased to 2.5 t/year from 54.4 t/year owing to application of digested slurry. Biogas generation rate increased from 52,125 Nm³/year to 326,822 Nm³/year. Remark is that the nitrogen loss from paddy field could be slightly increased by assumed scenario derived from ammonia volatilization in application of slurry to surface of paddy field. It is necessary to considerate the application way of slurry which can minimize the ammonia volatilization rate in the future.

3.3 Design for plan model 2; Production of bio-ethanol from unused rice straw

Plan model 2 was designed to effectively utilize unused rice straw of 1,618 t/year in rice cultivation. According to the result of experiment for making bio-ethanol from rice straw at a pilot plant on the site, 420 kL/year of bio-ethanol can be produced from 6,000 t/year of rice straw with a moisture content of 60%¹⁸⁾. Therefore, the conversion unit for bio-ethanol from rice straw can be calculated as 175 (L/t-dry rice straw).

By the above assumed scenario, the material flow in a village was calculated as shown in Fig. 4. This revealed that approximately 240 kL/year (≒ 190 t/y) of bio-ethanol can be produced as the regional energy from unused rice straw. Bio-ethanol could reduce GHG gas emission from fossil fuel substituted for bio-ethanol.

4. Conclusion

In this study, the basic model structure to diagnose region-basis material flow on biomass use was designed.

Fig. 4 “Plan model 2” based on the scenario of producing bio-ethanol from unused rice straw

Present conditions of biomass use focusing on livestock excreta treatment, rice cultivation and conditions of water quality in waterbodies were investigated. Necessary data and information were collected from literature review, interviews of farmers and public administrative staff and field surveys though the data mainly related to non-paddy fields should have been substituted by Japanese ones. The model that represents the present biomass use showed that untreated livestock excreta may cause water pollution, and some by-products from rice cultivation are not effectively used despite they are sources of energy if used effectively.

For this situation, 2 scenarios to improve the use of regional biomass were proposed. The first one proposed increasing the biogas digesters in the village for treatment of all untreated pig and milk cow excreta, decreasing the water poured into biogas digesters from 5 times volume of livestock excreta to the same volume as livestock excreta and using all the slurry at paddy and non-paddy fields as fertilizer. The second proposed using all of the unused rice straw as feedstock for bio-ethanol production.

Then, from 2 proposed scenarios, the possibilities were revealed that approximately 327,000 Nm³/year of biogas and more than 240 kL/year of bio-ethanol could be produced. Moreover, 39% of the nitrogen load to water bodies and the 95% of the application rate of chemical fertilizer to agricultural field could be decreased and greenhouse gas emission rate could be decreased if bioethanol is used as substitute for gasoline.

Actually, to introduce above proposed scenarios, various considerations and improvements are necessary, such as related to costs, energy and technology. The adoptability of the scenarios should be evaluated under the comparison of merit as benefit or effectiveness with adoption of a scenario with demerits such as high cost, high energy and other factors. Therefore, the method used in this study may contribute as the first step in selection of the best scenario for improvement of sustainable regional biomass use in the future.

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Appendix_1 Bases of data used for regional diagnosis (paddy field compartment)

Data required	Component	Specific value		Total amount		Process of calculation	Data/information sources	No.
		Value	Unit	Value	Unit			
Paddy field area	—	—	—	217.6	ha	Paddy cropping area in a year is 544 (ha/y)···(1) Half area is 2 (crops/y), and other half area is 3 (crops/y)···(1) Assumption that same size of area is used for each cultivation season, actual paddy field area is calculated as follows: Paddy field area (ha) = 544 (ha/y)/(1/2 (ha) * 2 (crops) + 1/2 (ha) * 3 (crops)) = 544 ((ha/y) * 2/5) = 217.6 (ha)	(1) Interviews of VPC, DARD	1
(Input) Application of chemical fertilizer	W	840	kg/ha/crop	457	t/y	Application rate of chemical fertilizer is 840 (kg/ha/crop)···(1) Therefore, chemical fertilizer rate (t/y) = Application rate of chemical fertilizer (kg/ha/crop) * Cropping area in a year (ha/y)/1000 = 840 (kg/ha/crop) * 544 (ha/y)/1,000 = 457 (t/y)	(1) Interviews of VPC and Villagers	2
	C	0	kg/ha/crop	0	t/y	Carbon is not contained in chemical fertilizer	—	-
	N	100	kg/ha/crop	54.4	t/y	Application rate of nitrogen fertilizer is 100 (kg/ha/crop)···(1) Therefore, application rate of nitrogen fertilizer (t/y) = Application rate of nitrogen fertilizer (kg/ha/crop) * Cropping area in a year (ha/y)/1,000 = 100 (kg/ha/crop) * 544 (ha/y)/1,000 = 54.4 (t/y)	(1) Interviews of VPC and Villagers	3
(Input) Precipitation	W	1881.8	mm/y	4,094,797	t/y	Mean annual precipitation is 1,881.8 (mm/y)···(1) Therefore, input from precipitation (t/y) = Mean annual precipitation (mm/y) * Area (ha) * 10 = 1,881.8 (mm/y) * 217.6 (ha) * 10 = 4,094,797 (t/y)	(1) Global Meteorological Information CD edited by Japan Meteorological Business Support Center	4
	C	1.9	mg/L	8	t/y	Total carbon concentration of precipitation is 1.9 (mg/L)···(1) Therefore, input from precipitation (t/y) = Total carbon concentration of precipitation (mg/L) * Precipitation rate (t/y)/1,000,000 = 1.9 (mg/L) * 4,094,797 (t/y)/1,000,000 = 8 (t/y)	(1) Hanya T. and Ogura N. (1985) : Water quality investigation method, p. 58, Maruzen	5
	N	1.1	mg/L	4.5	t/y	Total nitrogen concentration of precipitation is 1.1 (mg/L)···(1) Therefore, nitrogen content of precipitation (t/y) = Total nitrogen concentration of precipitation (mg/L) * Precipitation rate (t/y)/1,000,000 = 1.1 (mg/L) * 4,094,797 (t/y)/1,000,000 = 4.5 (t/y)	(1) Tabuchi T. and Takamura Y. (1985) : Discharge of nitrogen and phosphorus from watershed, p. 19, University of Tokyo Press	6

(Input) Irrigation water	W	10,286.28	t/ha/y	2,238,295	t/y	<p>Irrigation water for cultivation in dry season (from December to March) was 8,928.52 (t/ha/crop)··(1)</p> <p>precipitation in this season was 66 (mm), that is, 660 (t/ha/crop)··(2)</p> <p>Therefore, necessary water for rice cultivation per crop should be 9588.52 (t/ha/crop).</p> <p>Precipitation in spring-summer season (from April to August) is 1,128.5 (mm), that is, 11,285 (t/ha/crop) and precipitation in summer-autumn season (from September to November) is 687.3 (mm), that is, 6,873 (t/ha/crop)··(2)</p> <p>Therefore, necessary irrigation water for each season is 0 (t/ha/crop) and 2,715.52 (t/ha/crop), respectively.</p> <p>2 crops per year, that is, cultivation in dry season and spring-summer season is conducted in half of paddy field, and 3 crops per year, that is, cultivation in dry season, spring-summer season and summer-autumn season is conducted in half of paddy field··(3)</p> <p>Therefore, necessary quantity of annual irrigation water (t/ha/y)</p> $= 1/2 * (8,928.52 + 0) + 1/2 * (8,928.52 + 0 + 2,715.52)$ $= 10,286.28 \text{ (t/ha/y)}$ <p>Therefore, quantity of irrigation water (t/y)</p> $= 10,286.28 \text{ (t/ha/y)} * 217.6 \text{ (ha)}$ $\approx 2,238,295 \text{ (t/y)}$	<p>(1) Field survey at test field (from December 2011 to March 2012)</p> <p>(2) Global Meteorological Information CD edited by Japan Meteorological Business Support Center</p> <p>(3) Interviews of VPC and Villagers</p>	7
	C	4.0	mg/L	9	t/y	<p>Total carbon concentration of irrigation water is approximately 4.0 (mg/L)··(1)</p> <p>Therefore, carbon content of irrigation water (t/y)</p> $= \text{Quantity of irrigation water (t/y)} * \text{Carbon concentration of irrigation water (mg/L)/1,000,000}$ $= 2,238,295 \text{ (t/y)} * 4.0 \text{ (mg/L)/1,000,000}$ $\approx 9 \text{ (t/y)}$	<p>(1) Survey of surface water quality in canal in Thai My Village (from 2010 to 2012)</p>	8
	N	1.3	mg/L	2.9	t/y	<p>Total nitrogen concentration of irrigation water is approximately 1.3 (mg/L)··(1), (2)</p> <p>Therefore, nitrogen content of irrigation water (t/y)</p> $= \text{Quantity of irrigation water (t/y)} * \text{Nitrogen concentration of irrigation water (mg/L)/1,000,000}$ $= 2,238,295 \text{ (t/y)} * 1.3 \text{ (mg/L)/1,000,000}$ $\approx 2.9 \text{ (t/y)}$	<p>(1) Tabuchi T. et al. (1998) : Science for clean water, The Japanese Society of irrigation, Drainage and Rural Engineering</p> <p>(2) Survey of surface water quality in canal in Thai My Village (from 2010 to 2012)</p>	9
(Input) Photosynthesis	W	—	—	6,233	t/y	<p>Carbon is taken from the air as carbon dioxide as shown in the following formula for photosynthesis:</p> $6\text{CO}_2 + 12\text{H}_2\text{O} \rightarrow \text{C}_6\text{H}_{12}\text{O}_6 + 6\text{H}_2\text{O} + 6\text{O}_2$ <p>Therefore, photosynthesis rate (t/y)</p> $= 44/12 * \text{Carbon rate taken by photosynthesis (t/y)}$ $= 44/12 * 1,700 \text{ (t/y)}$ $\approx 6,233 \text{ (t/y)}$	Calculation based on the molecular formula for carbon dioxide	10
	C	—	—	1,700	t/y	<p>Assumption that carbon content taken for photosynthesis is equal to the carbon content of harvest, that is, total carbon content of unhulled rice (Total of polished rice, rice husk and rice bran) and rice straw.</p> <p>Therefore, carbon content taken for photosynthesis (t/y)</p> $= 1,700 \text{ (t/y)}$	Calculation based on carbon content of harvest (unhulled rice and rice straw) obtained by field survey at test field (from December 2011 to March 2012)	11
	N	0	—	0	t/y	Nitrogen is not provided by photosynthesis.	—	-
(Input) Nitrogen fixation	W	—	—	10	t/y	Weight is as same as nitrogen.	—	12
	C	0	—	0	t/y	Carbon is not provided by nitrogen fixation.	—	-
	N	0.0045	t/ha/y	9.7	t/y	<p>Nitrogen fixation rate = 17.8 (kg/ha/crop)··(1)</p> <p>Therefore, nitrogen fixation rate (t/ha/y)</p> $= 17.8 \text{ (kg/ha/crop)} * (1/2 * 2 \text{ crops} + 1/2 * 3 \text{ crops})/1000$ $= 0.0445 \text{ (t/ha/y)}$ <p>Nitrogen fixation rate (t/y)</p> $= \text{Nitrogen fixation rate (t/ha/y)} * \text{Area (ha)}$ $= 0.0445 \text{ (t/ha/y)} * 217.6 \text{ (ha)}$ $\approx 9.7 \text{ (t/y)}$	<p>(1) Giao T. Q. (2012) : Effects of rotational crops and water management on balance of N, P and K and characteristics of acidic alluvium soil, Doctoral Dissertation in Can Tho University, Vietnam</p>	13

(Output) Evapotranspiration	W	150	mm/month	3,642,624	t/y	<p>Average rate of evaporation at Ho Chi Minh City is 150 mm/month.···(1)</p> <p>The relationship between evapotranspiration and pan evaporation can be written as "evapotranspiration = 0.93 * pan evaporation".···(2)</p> <p>Therefore, evapotranspiration rate (t/y)</p> $= \text{Average of evaporation rate (mm/month)} * 12 (\text{month}) * 0.93 * \text{Area (ha)} * 10$ $= 150 (\text{mm/month}) * 12 (\text{month}) * 0.93 * 217.6 (\text{ha}) * 10$ $= 3,642,624 (\text{t/y})$	<p>(1) Hieu T. V. (2011) : Assessment of rain water resource in Ho Chi Minh City and proposal of management solutions. Report of DOST-HCMC project.</p> <p>(2) Yoshida S. (1978) : A simple evapotranspiration model of a paddy field in tropical Asia. Soil Science and Plant Nutrition, 25 (1), pp. 81-91</p>	14
(Output) Drainage	W	—	—	1,591,587	t/y	<p>Assumption that, quantity of drainage water (t/ha/y)</p> $= (\text{Quantity of irrigation water} + \text{Precipitation rate}) - (\text{Evapotranspiration rate} + \text{Percolation rate})$ <p>Therefore, quantity of drainage water (t/y)</p> $= (2,238,295 (\text{t/y}) + 4,094,797 (\text{t/y})) - (3,642,624 (\text{t/y}) + 1,098,880 (\text{t/y}))$ $\approx 1,591,587 (\text{t/y})$	Calculation based on quantity of irrigation water, precipitation rate, evapo-transpiration rate and percolation rate.	15
	C	8.0	mg/L	13	t/y	<p>Carbon concentration of drainage water is approximately twice as much as irrigation water, that is, 8.0 (mg/L).···(1)</p> <p>Therefore, carbon content of drainage water (t/y)</p> $= \text{Quantity of drainage water (t/y)} * \text{Total carbon concentration of drainage water (mg/L)/1,000,000}$ $= 1,591,587 (\text{t/y}) * 8.0 (\text{mg/L})/1,000,000$ $\approx 13 (\text{t/y})$	(1) Assumption based on the results of survey of surface water quality in canal in Thai My Village (from 2010 to 2012)	16
	N	2.6	mg/L	4.1	t/y	<p>Nitrogen concentration of drainage water is approximately twice as much as irrigation water, that is, 2.6 (mg/L).···(1)</p> <p>Therefore, nitrogen content of drainage water (t/y)</p> $= \text{Quantity of drainage water (t/y)} * \text{Total nitrogen concentration of drainage water (mg/L)/1,000,000}$ $= 1,591,587 (\text{t/y}) * 2.6 (\text{mg/L})/1,000,000$ $\approx 4.1 (\text{t/y})$	(1) Assumption based on the results of survey of surface water quality in canal in Thai My Village (from 2010 to 2012)	17
(Output) Denitrification	W	—	—	16	t/y	Weight is as same as nitrogen.	—	18
	C	0	—	0	t/y	Carbon is not lost by denitrification.	—	-
	N	30	%	16.3	t/y	<p>Denitrification rate is 20-50% of nitrogen fertilization rate.···(1)</p> <p>Therefore, assumption the value is 30%.</p> <p>Therefore, denitrification rate (t/y)</p> $= \text{Nitrogen content of fertilizer (kg/ha/crop)} * \text{Cropping area in a year (ha/y)} * 0.3/1,000$ $= 100 (\text{kg/ha/crop}) * 544 (\text{ha/y}) * 0.3/1,000$ $\approx 16.3 (\text{t/y})$	(1) Kyuma K. (2004) : Paddy soil science. Kyoto University Press, p. 151	19
(Output) Ammonia volatilization	W	—	—	1	t/y	Weight is as same as ammonia volatilization rate.	—	20
	C	0	—	0	t/y	Carbon is not lost by ammonia volatilization.	—	-
	N	1.7	%	0.9	t/y	<p>Nitrogen loss by ammonia volatilization is 1.7% of nitrogen fertilization rate per crop at paddy field with the pH range between 3.4 and 6.2.···(1)</p> <p>Therefore, nitrogen loss by ammonia volatilization (t/y)</p> $= \text{Nitrogen fertilization rate (kg/ha/crop)} * \text{Cropping area in a year (ha/y)} * 0.017/1,000$ $= 100 (\text{kg/ha/crop}) * 544 (\text{ha/y}) * 0.017/1,000$ $\approx 0.9 (\text{t/y})$	(1) Watanabe T. (2009) : Measurement of ammonia volatilization from flooded paddy fields in Vietnam. Soil Science and Plant Nutrition, 55, pp. 793-799	21
(Output) Percolation	W	202	mm / ha / crop	1,098,880	t/y	<p>1) Percolation rate is 202 (mm/ha/crop).···(1)</p> <p>Therefore, percolation rate (t/y)</p> $= \text{Percolation rate (mm/ha/crop)} * 0.01 * \text{Cropping area in a year (ha/y)} * 1,000$ $= 202 (\text{mm/ha/crop}) * 0.01 * 544 (\text{ha/y}) * 1,000$ $= 1,098,880 (\text{t/y})$	(1) Thoai N. L. Q et al. (2012) : Balance of water, nitrogen and phosphorus for rice crop at a paddy field in Southern Vietnam, Proceedings of annual conference for Society of Environmental Science 2012, Japan, pp. 136-137	22
	C	0	kg/ha/crop	0	t/y	Carbon loss by percolation is assumed to be 0.	—	-
	N	11	mg/L	12.1	t/y	<p>Nitrogen concentration of water 30-50 cm from the ground surface in the experimental field was approximately 11 (mg/L).···(1)</p> <p>Percolation rate is 1,098,880 (t/y).</p> <p>Therefore, loss by nitrate leaching (t/y)</p> $= \text{Percolation rate (t/y)} * \text{Nitrogen concentration in water (mg/L)/1,000,000}$ $= 1,098,880 (\text{t/y}) * 11 (\text{mg/L})/1,000,000$ $\approx 12.1 (\text{t/y})$	(1) Field survey at test field (from December 2013 to March 2014)	23

(Output) Methane gas emission	W	160	kg/ha/y	87	t/y	1) Methane gas emitted during cultivation of rice at intermittently flooded paddy field is approximately 16 g/m ² /y... (1) = 160 kg/ha/y Methane gas emission rate is 160 kg/ha/y in the reference. The rate is converted to 160 kg/ha/crop to applicate the rate to the objective village. Therefore, methane gas emission rate (t/y) = Methane gas emission rate (kg/ha/crop) * Cropping area in a year (ha/y)/1,000 = 160 (kg/ha/crop) * 544 (ha/y)/1,000 ≒ 87 (t/y)	(1) Ministry of Environment, Japan Greenhouse Gas Inventory Office of Japan (GIO), CGER, NIES (2011) : National Greenhouse Gas Inventory Report of Japan, p. 6-25	24
	C	—	—	65	t/y	Carbon content in methane gas (t/y) = Methane gas emission rate (t/y) * 12/16 = 87 * 12/16 ≒ 65 (t/y)	Calculation based on the molecular formula of methane	25
	N	0	kg/ha	0	t/y	Nitrogen is not lost by methane gas emission.	—	-
(Output) Carbon dioxide emission	W	—	—	2,952	t/y	Carbon dioxide emission rate (t/y) = 44/12 * Carbon loss rate in the form of carbon dioxide (t/y) ≒ 2,952 (t/y)	Calculation based on the molecular formula of carbon dioxide	26
	C	870	t/y	805	t/y	Total carbon loss from paddy field is 4,000 (kgC/ha/y)·(1). Therefore, total carbon loss from paddy field (t/y) = 4,000 (kg/ha/y) * 217.6 (ha)/1000 ≒ 870 (t/y). Assumption that carbon loss from the paddy field is in the form of methane and carbon dioxide. Therefore, carbon loss in the form of carbon dioxide (t/y) = Total carbon loss rate (t/y) - Carbon loss rate in the form of methane (t/y) = 870 (t/y) - 65 (t/y) = 805 (t/y).	(1) Systemization Sub-team, Bio-recycle Project ed. (2006) : Design and Evaluation of Biomass Use System, p. 33	27
	N	0	t/y	0	t/y	Nitrogen is not lost by carbon dioxide emissions.	—	-
(Output) Yield of polished rice (normal)	W	0.6161	—	1,341	t/y	Average yield of unhulled rice is 4 (t/ha/crop) with a water content of 15%... (1),(2) Generation rate of polished rice (normal) to yield of unhulled rice is 0.6161 with a water content of 15%... (1) Therefore, the amount of polished rice (normal) with the water content of 15% (t/y) = Yield of unhulled rice with a water content of 15% (t/ha/crop) * Cropping area in a year (ha/y) * Generation rate = 4 (t/ha/crop) * 544 (ha/y) * 0.6161 ≒ 1,341 (t/y)	(1) Field survey at test field (from December 2011 to March 2012, from May to August 2012) (2) Interviews of VPC and Villagers	28
	C	42.5	%	484	t/y	Carbon concentration of polished rice under dry conditions is about 42.5 (%)... (1) Therefore, carbon content of polished rice (normal) = Amount of polished rice (normal) with a water content of 15% (t/y) * (1-water content (%)) * Carbon concentration of polished rice under dry conditions (%) = 1,341 (t/y) * (1-15/100) * 42.5/100 ≒ 484 (t/y)	(1) Field survey at test field (from May to August 2012, from December 2013 to March 2014)	29
	N	1.2	%	13.7	t/y	Nitrogen concentration of polished rice under dry conditions is 1.2 (%)... (1) Therefore, nitrogen content of polished rice (normal) = Amount of polished rice (normal) with the water content of 15% (t/y) * (1-water content (%)) * Nitrogen concentration of polished rice (normal) under dry conditions (%) = 1,341 (t/y) * (1-15/100) * 1.2/100 ≒ 13.7 (t/y)	(1) Field survey at test field (from May to August 2012, December 2013 to March 2014)	30
(Output) Yield of polished rice (broken)	W	0.0967	—	210	t/y	Generation rate of polished rice (broken) to yield of unhulled rice is 0.0967 with a water content of 15%... (1) Therefore, the amount of polished rice (broken) with a water content of 15% (t/y) = Yield (t/ha/crop) * Cropping area in a year (ha/y) * Generation rate = 4 (t/ha/crop) * 544 (ha/y) * 0.0967 ≒ 210 (t/y)	(1) Field survey at test field (from December 2011 to March 2012, from May to August 2012)	31

(Output) Yield of polished rice (broken)	C	42.5	%	76	t/y	Carbon concentration of polished rice under dry conditions is 42.5 (%).∴(1) Therefore, carbon content of polished rice (broken) = Amount of polished rice (broken) with a water content of 15% (t/y) * (1-water content (%)) * Carbon concentration of polished rice (broken) under dry conditions (%) = 210 (t/y) * (1-15/100) * 42.5/100 ≒ 76 (t/y)	(1) Field survey at test field (from May to August 2012, from December 2013 to March 2014)	32
	N	1.2	%	2.1	t/y	Nitrogen concentration of polished rice under dry conditions is 1.2 (%).∴(1) Therefore, nitrogen content of polished rice (broken) = Amount of polished rice (broken) with a water content of 15% (t/y) * (1-water content (%)) * Nitrogen concentration of polished rice (broken) under dry conditions (%) = 210 (t/y) * (1-15/100) * 1.2/100 ≒ 2.1 (t/y)	(1) Field survey at test field (from May to August 2012, from December 2013 to March 2014)	33
(Output) Yield of rice husk	W	0.1995	—	434	t/y	Generation rate of rice husk to yield of unhulled rice is 0.1995 with a water content of 15%.∴(1) Therefore, the amount of rice husk with a water content of 15% (t/y) = Yield (t/ha/crop) * Cropping area in a year (ha/y) * Generation rate = 4 (t/ha/crop) * 544 (ha/y) * 0.1995 ≒ 434 (t/y)	(1) Field survey at test field (from December 2011 to March 2012, from May to August 2012)	34
	C	34.6	%	128	t/y	Carbon concentration of rice husk under dry conditions is 34.6 (%).∴(1) Therefore, carbon content of rice husk (t/y) = Amount of rice husk with the water content of 15% (t/y) * (1-water content (%)) * Carbon concentration of rice husk with dry conditions (%) = 434 (t/y) * (1-15/100) * 34.6/100 ≒ 128 (t/y)	(1) Nakamura M. et al. (2005) : Development of a composition database for various types of biomass, Technical Report of the National Institute for Rural Engineering, p. 69	35
	N	0.32	%	1.2	t/y	Nitrogen concentration of rice husk is 0.32 (%).∴(1). Therefore, nitrogen content of rice husk (t/y) = Amount of rice husk with a water content of 15% (t/y) * (1-water content (%)) * Nitrogen concentration of rice husk with dry conditions (%) = 434 (t/y) * (1-15/100) * 0.32/100 ≒ 1.2 (t/y)	(1) Nakamura M. et al. (2005) : Development of a composition database for various types of biomass, Technical Report of the National Institute for Rural Engineering, p. 69	36
	W	0.0877	—	191	t/y	Generation rate of rice bran to yield of unhulled rice with a water content of 15% is 0.0877∴(1). Therefore, the amount of rice bran with a water content of 15% (t/y) = Yield with a water content of 15% (t/ha/crop) * Cropping area in a year (ha/y) * Generation rate = 4 (t/ha/crop) * 544 (ha/y) * 0.0877 ≒ 191 (t/y)	(1) Field survey at test field (from December 2011 to March 2012, from May to August 2012)	37
(Output) Yield of rice bran	C	40.2	%	65	t/y	Carbon concentration of rice bran under dry conditions is 40.2 (%).∴(1) Therefore, carbon content of rice bran = Amount of rice bran with the water content of 15% (t/y) * (1-water content (%)) * Carbon concentration of rice bran with dry conditions (%) = 191 (t/y) * (1-15/100) * 40.2/100 ≒ 65 (t/y)	(1) Nakamura M. et al. (2005) : Development of a composition database for various types of biomass, Technical Report of the National Institute for Rural Engineering, p. 69	38
	N	1.18	%	1.9	t/y	Nitrogen concentration of rice bran under dry conditions is 1.18 (%).∴(1) Therefore, nitrogen content of rice bran = Amount of rice bran with the water content of 15% (t/y) * (1-water content (%)) * Nitrogen concentration of rice bran with dry conditions (%) = 191 (t/y) * (1-15/100) * 1.18/100 ≒ 1.9 (t/y)	1) Nakamura M. et al. (2005) : Development of a composition database for various types of biomass, Technical Report of the National Institute for Rural Engineering, p. 69	39

(Output) Yield of rice straw (Upper part above dividing point at harvesting)	W	1.1154	—	2,427	t/y	Generation rate of upper part above dividing point by combine or hook at harvesting of rice straw to yield of unhulled rice is 1.1154:...(1),(2) Therefore, the amount of rice straw (upper part) (t/y) = Yield (t/ha/crop) * Cropping area in a year (ha/y) * Generation rate = 4 (t/ha/crop) * 544 (ha/y) * 1.1154 $\approx$ 2,427 (t/y)	(1) Field survey at test field (from December 2011 to March 2012, from May to August 2012) (2) Interviews of Villagers	40
	C	37.01	%	764	t/y	Carbon concentration of rice straw under dry conditions is 37.01 (%):...(1) Therefore, carbon content of rice straw (upper part) = Amount of rice straw (upper part) with a water content of 15% (t/y) * (1-water content (%)) * Carbon concentration of rice straw under dry conditions (%) = 2,427 (t/y) * (1-15/100) * 37.01/100 $\approx$ 764 (t/y)	(1) Field survey at test field (from December 2011 to March 2012, from May to August 2012)	41
	N	0.66	%	13.6	t/y	Nitrogen concentration of rice straw under dry conditions is 0.66 (%):...(1) Therefore, nitrogen content of rice straw (upper part) = Amount of rice straw (upper part) (t/y) * (1-water content (%)) * Nitrogen concentration of rice straw under dry conditions (%) = 2,427 (t/y) * (1-15/100) * 0.66/100 $\approx$ 13.6 (t/y)	(1) Field survey at test field (from December 2011 to March 2012, from May to August 2012)	42
(Output) Yield of rice straw (Lower part below dividing point at harvesting)	W	0.2676	—	582	t/y	Generation rate of lower part below dividing point by combine or hook of rice straw to yield of unhulled rice is 0.2676:...(1),(2) Therefore, the amount of rice straw (lower part) (t/y) = Yield (t/ha/crop) * Cropping area in a year (ha/y) * Generation rate = 4 (t/ha/crop) * 544 (ha/y) * 0.2676 $\approx$ 582 (t/y)	(1) Field survey at test field (from December 2011 to March 2012, from May to August 2012) (2) Interviews of Villagers	43
	C	37.01	%	183	t/y	Carbon concentration of rice straw under dry conditions is 37.01 (%):...(1) Therefore, carbon content of rice straw (lower part) = Amount of rice straw (lower part) (t/y) * (1-water content (%)) * Carbon concentration of rice straw under dry conditions (%) = 582 (t/y) * (1-15/100) * 37.01/100 $\approx$ 183 (t/y)	(1) Field survey at test field (from December 2011 to March 2012, from May to August 2012)	44
	N	0.66	%	3.3	t/y	Nitrogen concentration of rice straw under dry conditions is 0.66 (%):...(1) Therefore, nitrogen content of rice straw = Amount of rice straw (lower part) (t/y) * (1-water content (%)) * Nitrogen concentration of rice straw under dry conditions (%) = 582 (t/y) * (1-15/100) * 0.66/100 $\approx$ 3.3 (t/y)	(1) Field survey at test field (from December 2011 to March 2012, from May to August 2012)	45
(Output) Ammonia volatilization (With use of slurry)	W	—	—	3	t/y	Weight is same as ammonia vitalization rate.	—	46
	C	0	—	0	t/y	Carbon is not lost by ammonia volatilization.	—	-
	N	4.86	%	2.6	t/y	Nitrogen loss by ammonia volatilization is 1.7% of nitrogen fertilization rate per crop at paddy field with the pH range between 3.4 and 6.2:...(1) By laboratory test on application of chemical fertilizer and slurry to soil in experimental paddy field (pH 3.5-4.0), the ammonia volatilization rate in the application of slurry was 2.857 times greater than in chemical fertilizer:...(2) Therefore, nitrogen loss by ammonia volatilization (t/y) = Nitrogen content of fertilizer (kg/ha/crop) * Cropping area in a year (ha/y) * 0.017/1,000 * 2.857 = 100 (kg/ha/crop) * 544 (ha/y) * 0.017/1,000 * 2.857 $\approx$ 2.6 (t/y)	(1) Watanabe T. (2009) : Measurement of ammonia volatilization from flooded paddy fields in Vietnam. Soil Science and Plant Nutrition, 55, pp. 793-799 (2) Laboratory-test	47

(Output) Gas emission in burning unused rice straw after harvesting (Without use of rice straw for bio-ethanol)	W	—	—	2,250	t/y	<p>Rice straw burned after cultivation is the total of all lower part below dividing point, and 4/6 of upper part above dividing point by combine or hook... (1)</p> <p>Therefore, the amount of burned rice straw (t/y)</p> $= 582 \text{ (t/y)} + 4/6 * 2,427 \text{ (t/y)}$ $= 2,200 \text{ (t/y)}$ <p>The contribution to the gaseous C released to the atmosphere is 84% for CO₂, 14% for CO and 1.2% for CH₄... (2)</p> <p>Total carbon loss is 657 (t/y) as below calculation about carbon rate.</p> <p>Therefore, carbon loss by CO₂ (t/y)</p> $= 657 \text{ (t/y)} * 0.84$ $\approx 552 \text{ (t/y)}$ <p>Carbon loss by CO (t/y)</p> $= 657 \text{ (t/y)} * 0.14$ $\approx 92 \text{ (t/y)}$ <p>Carbon loss by CH₄ (t/y)</p> $= 657 \text{ (t/y)} * 0.012$ $\approx 8 \text{ (t/y)}$ <p>Therefore, the weight of gas released in burning the rice straw (t/y)</p> $= \text{Total of loss in the form of CO}_2, \text{ CO and CH}_4$ $= 552 \text{ (t/y)} * 44/12 + 92 \text{ (t/y)} * 28/12 + 8 * 16/12$ $\approx 2,250 \text{ (t/y)}$	(1) Field survey at test field (from December 2011 to March 2012, from May to August 2012) (2) Nguyen B. C. et al. (1994) : CH ₄ and CO emissions from rice straw burning in south east Asia, Environmental Monitoring and Assessment 31, pp. 131-137	48
	C	37.01	%	657	t/y	<p>Carbon concentration of rice straw under dry conditions is 37.01 (%)... (1)</p> <p>Therefore, carbon content of 2,200 (t/y) of rice straw (t/y)</p> $= \text{Amount of rice straw with a water content of 15\% (t/y)} * (1 - \text{water content (\%)}) * \text{Carbon concentration of rice straw under dry conditions (\%)}$ $= 2,200 \text{ (t/y)} * (1 - 15/100) * 37.01/100$ $\approx 692 \text{ (t/y)}$ <p>3) About 95% of the carbon burned is released in the atmosphere in the gaseous form... (2)</p> <p>4) Therefore, carbon loss rate by burning of rice straw (t/y)</p> $= 692 \text{ (t/y)} * 0.95$ $\approx 657 \text{ (t/y)}$	(1) Field survey at test field (from December 2011 to March 2012, from May to August 2012) (2) Nguyen B. C. et al. (1994) : CH ₄ and CO emissions from rice straw burning in south east Asia, Environmental Monitoring and Assessment 31, pp. 131-137	49
	N	—	—	0	t/y	Nitrogen is not lost.	—	-
(Output) Gas emission in burning unused rice straw after harvesting (With use of rice straw for bio-ethanol)	W	—	—	594	t/y	<p>Rice straw burned after cultivation is the total of all lower part below dividing point.</p> <p>Therefore, the amount of burned rice straw (t/y)</p> $= 582 \text{ (t/y)} \dots (1)$ <p>The contribution to the gaseous C released to the atmosphere is 84% for CO₂, 14% for CO and 1.2% for CH₄... (2)</p> <p>Total carbon loss is 174 (t/y) as below calculation about carbon rate.</p> <p>Therefore, carbon loss by CO₂ (t/y), CO (t/y) and CH₄ (t/y)</p> $\approx 146 \text{ (t/y)}, 24 \text{ (t/y)} \text{ and } 2 \text{ (t/y)}$ <p>Therefore, the weight of gas released in burning the rice straw (t/y)</p> $= \text{Total of loss in the form of CO}_2, \text{ CO and CH}_4$ $= 146 \text{ (t/y)} * 44/12 + 24 \text{ (t/y)} * 28/12 + 2 * 16/12$ $= 594 \text{ (t/y)}$	(1) Field survey at test field (from December 2011 to March 2012, from May to August 2012) (2) Nguyen B. C. et al. (1994) : CH ₄ and CO emissions from rice straw burning in south east Asia, Environmental Monitoring and Assessment 31, pp. 131-137	50
	C	37.01	%	174	t/y	<p>Carbon concentration of rice straw under dry conditions is 37.01 (%)... (1)</p> <p>Therefore, carbon content of 582 (t/y) of rice straw (t/y)</p> $= \text{Amount of rice straw with a water content of 15\% (t/y)} * (1 - \text{water content (\%)}) * \text{Carbon concentration of rice straw under dry conditions (\%)}$ $= 582 \text{ (t/y)} * (1 - 15/100) * 37.01/100$ $\approx 183 \text{ (t/y)}$ <p>About 95% of the carbon burned is released in the atmosphere in the gaseous form... (2)</p> <p>Therefore, carbon loss rate by burning of rice straw (t/y)</p> $= 183 \text{ (t/y)} * 0.95$ $\approx 174 \text{ (t/y)}$	(1) Field survey at test field (from December 2011 to March 2012, from May to August 2012) (2) Nguyen B. C. et al. (1994) : CH ₄ and CO emissions from rice straw burning in south east Asia, Environmental Monitoring and Assessment 31, pp. 131-137	51
	N	—	—	0	t/y	Nitrogen is not lost.	—	-

Appendix_2 Bases of data used for regional diagnosis (non-paddy field compartment)

Data required	Component	Specific value		Total amount		Process of calculation	Data/information sources	No.
		Value	Unit	Value	Unit			
Total area	—	—	—	421	ha	—	Interviews of VPC, DARD	1
Corn cultivation area	—	—	—	200	ha	—	Interviews of VPC, DARD	2
(Input) Application of chemical fertilizer for corn	W	3,500	kg/ha/y	700	t/y	Chemical fertilization rate is 10 times nitrogen fertilization rate.	Rough assumption	3
	C	0	kg/ha/y	0	t/y	Carbon is not contained in chemical fertilizer.	—	-
	N	350	kg/ha/y	70.0	t/y	Fertilization standard for corn in Okinawa Prefecture is referred here because standard about corn in Vietnam is not clear. Fertilization with chemical fertilizer is "N : P ₂ O ₅ : K ₂ O = 35 : 19 : 20 (Unit: kg/10a/y)":...(1) Therefore, nitrogen fertilization rate with chemical fertilizer (t/y) = 350 (kg/ha/y) * 200 (ha)/1,000 = 70.0 (t/y)	(1) Guideline for vegetable cultivation in Okinawa Prefecture (2006) : Department of Agriculture, Forestry and Fisheries, Okinawa Prefecture, p. 7	4
	W	25	t/ha/y	5,000	t/y	Compost is used for cultivation of corn:...(1) Fertilization standard for corn in Okinawa Prefecture is referred here because standard for corn in Vietnam is not clear. Fertilization with compost is 2,500 kg/10a/y:...(2) Therefore, application rate of compost (t/y) = Fertilization rate with compost (t/ha/y) * Area (ha) = 25 (t/ha/y) * 200 (ha) = 5,000 (t/y) * In case of using digested slurry as fertilizer, application rate of compost would be decreased.	(1) Interviews of Villagers (2) Guideline for vegetable cultivation in Okinawa Prefecture (2006) : Department of Agriculture, Forestry and Fisheries, Okinawa Prefecture, p. 7	5
(Input) Application of compost for corn	C	18.36	%	918	t/y	Ratio of carbon to nitrogen is 18, and nitrogen concentration is 1.02 (%):...(1) Therefore, carbon concentration in dry compost is 18.36 (%). Therefore, application rate (t/y) = Application rate (t/y) * Carbon concentration of compost (%) = 5,000 (t/y) * 18.36/100 = 918 (t/y) * In case of using digested slurry as fertilizer, the application rate of compost would be decreased.	(1) Kin organic compost center industry Ltd. http://kin-taihi.jp/product.html	6
	N	1.02	%	51.0	t/y	Nitrogen concentration in compost is 1.02 (%):...(1) Therefore, application rate of nitrogen with compost (t/y) = Application rate of compost (t/y) * Nitrogen concentration of compost (%) = 5,000 (t/y) * 1.02/100 = 51.0 (t/y) * In case of using digested slurry as fertilizer, the application rate of compost would be decreased.	Kin organic compost center industry Ltd. http://kin-taihi.jp/product.html	7
	—	—	—	75	ha	—	Interviews of VPC, DARD	8
(Input) Application of chemical fertilizer for vegetables (sugar cane)	W	2,560	kg/ha/y	192	t/y	Chemical fertilization rate is 10 times nitrogen fertilization rate.	Rough assumption	9
	C	0	kg/ha/y	0	t/y	Carbon is not contained in chemical fertilizer.	—	-
	N	256	kg/ha/y	19.2	t/y	Vegetable variety cultivated at Thai My Village is not clear because vegetable variety is decided according to the price year by year:...(1) Sugar cane is one of the main vegetables cultivated in Vietnam...(2) and also in Thai My Village...(1), so assumption is sugar cane as main vegetable here. Fertilization standard for sugar cane in Okinawa Prefecture is referred here because standard for sugar cane in Vietnam is not clear. Fertilization by chemical fertilizer is "N : P ₂ O ₅ : K ₂ O = 25.6 : 23.2 : 10.9 (Unit: kg/10a/y) on average":...(3) Therefore, nitrogen fertilization rate with chemical fertilizer (t/y) = 25.6 (kg/10a/y) * 10 * Area (ha)/1,000 = 19.2 (t/y)	(1) Interviews of VPC and Villagers (2) Statistical Year Book 2011 (2011) : General Statistical Office in Vietnam, pp. 322-324 (3) Guideline for sugar cane cultivation (2006) : Department of Agriculture, Forestry and Fisheries, Okinawa Prefecture	10
	—	—	—	146	ha	—	Interviews of VPC, DARD	11

(Input) Application of chemical fertilizer for fruit (mango)	W	4,000	kg/ha/y	584	t/y	Fruit variety cultivated at Thai My Village is not clear because decided according to the price year by year.···(1) Mango is one of the main fruits cultivated in Vietnam···(2) and also in Thai My Village···(1), so assumption is mango as the main fruit here. Fertilization standard for mango (five years after starting cultivation) in Okinawa Prefecture is used here because standard for mango in Vietnam is not clear. Fertilization by chemical fertilizer is total fertilization rate in a year of 400 (kg/10a)···(3) Therefore, chemical fertilization rate (t/y) = Fertilization rate (kg/ha/y) * 10 * Area (ha)/1,000 = 4,000 (kg/ha/y) * 146 (ha)/1,000 = 584 (t/y)	(1) Interviews of VPC and Villagers (2) Statistical Year Book 2011 (2011) : General Statistical Office in Vietnam, pp. 372-374 (3) Guideline for fruits cultivation, (2003) : Department of Agriculture, Forestry and Fisheries, Okinawa Prefecture, p. 10	12
	C	0	kg/ha/y	0	t/y	Carbon is not contained in chemical fertilizer.	—	-
	N	200	kg/ha/y	29.2	t/y	Fertilization standard for mango (five years after starting cultivation) in Okinawa Prefecture is used here because standard for mango in Vietnam is not clear. Nitrogen fertilization rate shown in above standard is 20 (kg/10a) in a year···(1) Therefore, nitrogen fertilization rate of chemical fertilizer (t/y) = Nitrogen fertilization rate (kg/ha/y) * Area (ha)/1,000 = 200 (kg/ha/y) * 146 (ha)/1,000 = 29.2 (t/y)	(1) Guideline for fruits cultivation, (2003) : Department of Agriculture, Forestry and Fisheries, Okinawa Prefecture, p. 10	13
(Output) Yield of corn	W	7.5	t/ha/y	1,500	t/y	Yield of corn per crop is 6-9 (t/ha)···(1), so, the average is 7.5 (t/ha/crop). Corn is cultivated once a year, so, 7.5 (t/ha/crop) = 7.5 (t/ha/y). Therefore, yield (t/y) = yield (t/ha/y) * Area (ha) = 7.5 (t/ha/y) * 200 (ha) = 1,500 (t/y)	(1) Interviews of VPC and Villagers	14
	C	43.8	%	399	t/y	Carbon concentration of corn under dry conditions is 43.8%···(1) Assumption that water content of corn in above yield is 39.2%···(1) Therefore, carbon content with a water content of 39.2% (t/y) = Yield with the water content of 39.2% (t/y) * (1-water content (%)) * Carbon concentration under dry conditions (%) = 1,500 (t/y) * (1-39.2/100) * 43.8/100 = 399 (t/y)	(1) Nakamura M. et al. (2005) : Development of a composition database for various types of biomass, Technical Report of the National Institute for Rural Engineering, p. 70	15
	N	2.12	%	19.3	t/y	Nitrogen concentration under dry conditions is 2.12%···(1) Assumption that water content of corn in above yield is 39.2%···(1) Therefore, nitrogen content with a water content of 39.2% (t/y) = Yield of corn with the water content is 39.2% (t/y) * (1-water content (%)) * Nitrogen concentration under dry conditions (%) = 1,500 (t/y) * (1-39.2/100) * 2.12/100 = 19.3 (t/y)	(1) Nakamura M. et al. (2005) : Development of a composition database for various types of biomass, Technical Report of the National Institute for Rural Engineering, p. 70	16
(Output) Yield of sugar cane	W	62.95	t/ha/y	4,721	t/y	Yield of sugar cane in Ho Chi Minh City is 132,200 (t/y) when the cultivation area is 2,100 (ha)···(1) Therefore, calculating as 132,200 (t/y)/2,100 (ha) = 62.95 (t/ha/y). Therefore, yield of sugar cane (t/y) = Yield (t/ha/y) * Area (ha) = 62.95 (t/ha/y) * 75 (ha) = 4,721 (t/y)	(1) Statistical Year Book 2011 (2011) : General Statistical Office in Vietnam, pp. 366-367	17
	C	42.5	%	1,810	t/y	Carbon concentration under dry conditions is 42.5%···(1) Assumption that water content of sugar cane in above yield is 9.8%···(1) Therefore, carbon content with a water content of 9.8% (t/y) = Yield of sugar cane (t/y) * (1-water content (%)) * Carbon concentration under dry conditions (%) = 4,721 (t/y) * (1-9.8/100) * 42.5/100 = 1,810 (t/y)	(1) Nakamura M. et al. (2005) : Development of a composition database for various types of biomass, Technical Report of the National Institute for Rural Engineering, p. 70	18
	N	0.8	%	34.1	t/y	Nitrogen concentration of sugar cane under dry conditions is 0.8%···(1) Assumption that water content of sugar cane in above yield is 9.8%···(1) Therefore, nitrogen content of sugar cane with a water content of 9.8% (t/y) = Yield of sugar cane (t/y) * (1-water content (%)) * Nitrogen concentration of sugar cane (%) = 4,721 (t/y) * (1-9.8/100) * 0.8/100 = 34.1 (t/y)	(1) Nakamura M. et al. (2005) : Development of a composition database for various types of biomass, Technical Report of the National Institute for Rural Engineering, p. 70	19

(Output) Yield of mango	W	0.824	t/ha/y	120	t/y	Yield of mango in Vietnam is 71,200 (t/y) when the cultivation area is 86,400 (ha):...(1) Therefore, calculating as 71,200 (t/y)/86,400 (ha) = 0.824 (t/ha/y). Therefore, Yield (t/y) = Yield (t/ha/y) * Area (ha) = 0.824 (t/ha/y) * 146 (ha) ≈ 120 (t/y)	(1) Statistical Year Book 2011 (2011) : General Statistical Office in Vietnam. pp. 372-373	20
	C	40	%	9	t/y	Assumption that carbon concentration is 40%, because carbon concentration of other plants under dry conditions is about 40%:...(1) Assumption that water content of mango in above yield is 82%...(2) Therefore, carbon content (t/y) = Yield of mango with the water content of 82% (t/y) * (1-water content (%)) * Carbon concentration of mango (%) = 120 (t/y) * (1-82/100) * 40/100 ≈ 9 (t/y)	(1) Nakamura M. et al. (2005) : Development of a composition database for various types of biomass, Technical Report of the National Institute for Rural Engineering, pp. 69-70 (2) Kagawa Y. ed (2003) : Food component table, Kagawa Education Institute of Nutrition Press, p. 118	21
	N	0.096	%	0.0	t/y	Protein content of mango is 0.6%:...(1) Coefficient of nitrogen concentration to protein content is 6.25.(1) Therefore, nitrogen concentration of mango = 0.6/6.25 = 0.096 %. Assumption that water content of mango in above yield is 82%(1) Therefore, nitrogen content of mango with a water content of 82% (t/y) = Yield of mango (t/y) * (1-water content (%)) * Nitrogen concentration of mango (%) = 120 (t/y) * (1-82/100) * 0.096/100 (%) ≈ 0.0 (t/y)	(1) Kagawa Y. ed (2003) : Food component table, Kagawa Education Institute of Nutrition Press, p. 118, p. 255	22
(Input) Precipitation	W	1881.8	mm/y	7,922,378	t/y	Mean annual precipitation is 1881.8 (mm/y):...(1) Therefore, input from precipitation (t/y) = Mean annual precipitation (mm/y) * Area (ha) * 10 = 1881.8 (mm/y) * 421 (ha) * 10 = 7,922,378 (t/y)	(1) Global Meteorological Information CD edited by Japan Meteorological Business Support Center	23
	C	1.9	mg/L	15	t/y	Total carbon concentration of precipitation is 1.9 (mg/L):...(1) Therefore, input from precipitation (t/y) = Total carbon concentration of precipitation (mg/L) * Precipitation rate (t/y)/1,000,000 = 1.9 (mg/L) * 7,922,378 (t/ha)/1,000,000 ≈ 15 (t/y)	(1) Hanya T. and Ogura N. (1985) : Water quality investigation method, p. 58, Maruzen.	24
	N	1.1	mg/L	8.7	t/y	Total nitrogen concentration of precipitation is 1.1 (mg/L):...(1) Therefore, input from precipitation (t/y) = Total nitrogen concentration of precipitation (mg/L) * Precipitation rate (t/y)/1,000,000 = 1.1 (mg/L) * 7,922,378 (t/ha)/1,000,000 ≈ 8.7 (t/y)	(1) Tabuchi T. and Takamura Y. (1985) : Discharge of nitrogen and phosphorus from watershed, p. 19, University of Tokyo Press.	25
(Input) Photosynthesis	W	—	—	8,133	t/y	Carbon is provided from the air as carbon dioxide by the following formula for photosynthesis; $6\text{CO}_2 + 12\text{H}_2\text{O} \rightarrow \text{C}_6\text{H}_{12}\text{O}_6 + 6\text{H}_2\text{O} + 6\text{O}_2$ Therefore, photosynthesis rate (t/y) = $44/12$ * Carbon rate taken by photosynthesis (t/y) ≈ 8,133 (t/y)	Calculation based on the molecular formula of carbon dioxide	26
	C	2,218	t/y	2,218	t/y	Assumption that carbon content provided by photosynthesis is equal to the carbon content of harvest Therefore, 2,218 (t/y)	Calculation by sum of carbon content of harvested corn, sugar cane and mango.	27
	N	0	t/y	0	t/y	Nitrogen is not provided by photosynthesis.	—	-
(Input) Nitrogen fixation	W	—	—	44	t/y	Weight is as same as nitrogen fixation rate.	—	28
	C	0	t/y	0	t/y	Carbon is not provided by nitrogen fixation.	—	-
	N	105	kg/ha/y	44.2	t/y	Nitrogen fixation rate is 10-200 (kg/ha/y):...(1), so, the average value is 105 (kg/ha/y). Therefore, nitrogen fixation rate (t/y) = Nitrogen fixation rate (kg/ha/y) * Area (ha)/1,000 = 105 (kg/ha/y) * 421 (ha)/1,000 ≈ 44.2 (t/y)	(1) Systemization Sub-team, Bio-recycle Project ed. (2006) : Design and Evaluation of Biomass Use System, pp. 30-39	29

(Output) Nitrogen loss by emission (Both ammonia volatilization and denitrification)	W	—	—	8	t/y	Weight is almost as same as nitrogen loss rate by emission.	—	30
	C	0	t/y	0	t/y	Carbon is not lost by both ammonia volatilization and denitrification.	—	-
	N	18	kg/ha/y	7.6	t/y	Nitrogen loss rate by emission is 5-30 (kg/ha/y)···(1), the average value is 18 (kg/ha/y). Therefore, nitrogen loss rate by emission (t/y) = Nitrogen loss rate by emission (kg/ha/y) * Area (ha)/1,000 = 18 (kg/ha/y) * 421 (ha)/1,000 ≒ 7.6 (t/y)	(1) Systemization Sub-team, Bio-recycle Project ed. (2006) : Design and Evaluation of Biomass Use System, pp. 30-39	31
(Output) Carbon dioxide emission	W	—	—	3,859	t/y	Assumption that carbon loss is in the form of carbon dioxide. Therefore, carbon dioxide emission (t/y) = 44/12 * Carbon loss (t/y) ≒ 3,859 (t/y)	Calculation based on the molecular formula of carbon dioxide	32
	C	2,500	kgC/ha/y	1,053	t/y	Carbon loss is 1,500-3,500 (kgC/ha/y)···(1), the average value is 2,500 (kgC/ha/y). Therefore, carbon loss (t/y) = Carbon loss rate (kg/ha/y) * Area (ha)/1,000 = 2,500 (kg/ha/y) * 421 (ha)/1,000 ≒ 1,053 (t/y)	(1) Systemization Sub-team, Bio-recycle Project ed. (2006) : Design and Evaluation of Biomass Use System, pp. 30-39	33
	N	0	t/y	0	t/y	Nitrogen is not lost by carbon dioxide emissions.	—	-
(Output) Evapotranspiration	W	—	—	5,545,665	t/y	Assumption that 70% of precipitation is evapotranspiration, Evapotranspiration rate (t/y) = 0.7 * Precipitation rate (t/y) = 0.7 * 7,922,378 ≒ 5,545,665(t/y)	Rough assumption	34
(Output) Percolation	W	—	—	2,377,969	t/y	Assumption that percolation rate (t/y) = Precipitation rate (t/y) + (Application rate of digested slurry (using digested slurry because the water content of digested slurry is greater than 98%) - Evapotranspiration rate (t/y) ≒ 2,377,969 (t/y) (Case that 1,255 (t/y) of digested slurry is used)	Rough assumption	35
	C	0	t/y	0	t/y	Carbon is not lost by denitrification.	—	-
	N	169.4	t/y	50.8	t/y	Nitrate leaching rate is 20-40%···(1), so the average is 30%. Therefore, nitrate leaching rate (t/y) = Nitrogen fertilization rate (t/y) * 0.3 = 169.4 (t/y) * 0.3 ≒ 50.8 (t/y) *Here, nitrogen fertilization indicates by chemical fertilizer, compost and slurry.	(1) Systemization Sub-team, Bio-recycle Project ed. (2006) : Design and Evaluation of Biomass Use System, pp. 30-39	36

Appendix_3 Bases of data used for regional diagnosis (livestock wastes compartment)

Data required	Component	Specific value		Total amount		Process of calculation	Data/information sources	No.
		Value	Unit	Value	Unit			
Number of pigs	—	—	—	11,000	head	—	Interviews of VPC and Villagers	1
Generation rate of feces (pig)	W	0.73	t/head/y	8,030	t/y	Generation rate is 1.0-3.0 (kg/head/d)···(1), so the average is 2.0 (kg/head/d) = 0.73 (t/head/y) Therefore, raw weight (t/y) = Generation rate (t/head/y) * Numbers (head) = 0.73 * 11,000 = 8,030 (t/y)	(1) Nguyen T. H. L. (1994) : Study on pollutants in wastes from medium-scale pig farms and application of waste treatment methods for the piggery farms, Doctoral dissertation, Nong Lam University in Ho Chi Minh City	2
	C	18.68	%	459	t/y	Ratio of carbon to nitrogen is 20-25, and nitrogen concentration under dry conditions is 0.83 (%)···(1) Therefore, carbon concentration in dry conditions is 18.68 (%) in average. Water content of raw feces is 69.4 (%)···(2) Therefore, carbon content = Raw weight (t/y) * (1-water content (%)) * Carbon concentration under dry conditions (%) = 8,030 (t/y) * (1-69.4/100) * 18.68/100 ≈ 459 (t/y)	(1) Ngo K. S. and Nguyen L. D. (1997) : Biogas production using anaerobic digestion, Book of Agriculture Publishing House, Ho Chi Minh City (2) Nakamura M. et al. (2005) : Development of a composition database for various types of biomass, Technical Report of the National Institute for Rural Engineering, pp. 57-80	3
	N	0.83	%	20.4	t/y	Nitrogen concentration under dry conditions is 0.83 (%)···(1) Water content of raw feces is 69.4 (%)···(2) Therefore, nitrogen content = Raw weight (t/y) * (1-water content (%)) * Nitrogen concentration under dry conditions (%) = 8,030 (t/y) * (1-69.4/100) * 0.83/100 ≈ 20.4 (t/y)	(1) Ngo K. S. and Nguyen L. D. (1997) : Biogas production using anaerobic digestion, Book of Agriculture Publishing House, Ho Chi Minh City (2) Nakamura M. et al. (2005) : Development of a composition database for various types of biomass, Technical Report of the National Institute for Rural Engineering, pp. 57-80	4
Generation rate of urine (pig)	W	0.49	t/head/y	5,390	t/y	Generation rate is 0.7-2.0 (kg/head/d)···(1), so the average is 1.35 (kg/head/d) ≈ 0.49 (t/head/y). Therefore, raw weight (t/y) = Generation rate (t/head/y) * Numbers (head) = 0.49 * 11,000 = 5,390 (t/y)	(1) Nguyen T. H. L. (1994) : Study on pollutants in wastes from medium-scale pig farms and application of waste treatment methods for the piggery farms, Doctoral dissertation, Nong Lam University in Ho Chi Minh City	5
	C	0	—	0	t/y	Carbon is not contained in urine.	—	—
	N	32.5	%	35.0	t/y	Nitrogen concentration under dry conditions is 32.5%, and water content of raw urine is 98.0%···(1) Therefore, nitrogen content = Raw weight (t/y) * (1-water content (%)) * Nitrogen concentration under dry conditions (%) = 5,390 (t/y) * (1-98.0/100) * 32.5/100 ≈ 35.0 (t/y)	(1) Nakamura M. et al. (2005) : Development of a composition database for various types of biomass, Technical Report of the National Institute for Rural Engineering, pp. 57-80	6
Number of beef	—	—	—	1,659	head	—	Interviews of VPC and Villagers	7

Generation rate of feces (beef)	W	8.22	t/head/y	13,637	t/y	Generation rate is 20-25 (kg/head/d)···(1), so the average is 22.5 (kg/head/d) = 8.22 (t/head/y). Therefore, raw weight (t/y) = Generation rate (t/head/y) * Numbers (head) = 8.22 * 1,659 = 13,637 (t/y)	(1) Nguyen T. H. L. (1994) : Study on pollutants in wastes from medium-scale pig farms and application of waste treatment methods for the piggery farms, Doctoral dissertation, Nong Lam University in Ho Chi Minh City	8
	C	15.75	%	427	t/y	Ratio of carbon to nitrogen is 20-25, and nitrogen concentration under dry conditions is 0.7 (%)···(1). Therefore, carbon concentration under dry conditions is 15.75 (%) in average. Water content of raw feces is 80.1 (%)···(2). Therefore, carbon content = Raw weight (t/y) * (1-water content (%)) * Carbon concentration under dry conditions (%) = 13,637 (t/y) * (1-80.1/100) * 15.75/100 = 427 (t/y)	(1) Ngo K. S. and Nguyen L. D. (1997) : Biogas production using anaerobic digestion, Book of Agriculture Publishing House, Ho Chi Minh City (2) Nakamura M. et al. (2005) : Development of a composition database for various types of biomass, Technical Report of the National Institute for Rural Engineering, pp. 57-80	9
	N	0.7	%	19.0	t/y	Nitrogen concentration under dry conditions is 0.7 (%)···(1) Water content of raw feces is 80.1 (%)···(2) Therefore, nitrogen content = Raw weight (t/y) * (1-water content (%)) * Nitrogen concentration under dry conditions (%) = 13,637 (t/y) * (1-80.1/100) * 0.7/100 = 19.0 (t/y)	(1) Ngo K. S. and Nguyen L. D. (1997) : Biogas production using anaerobic digestion, Book of Agriculture Publishing House, Ho Chi Minh City (2) Nakamura M. et al. (2005) : Development of a composition database for various types of biomass, Technical Report of the National Institute for Rural Engineering, pp. 57-80	10
Generation rate of urine (beef)	W	4.56	t/head/y	7,565	t/y	Generation rate is 10-15 (kg/head/d)···(1), so the average is 12.5 (kg/head/d) = 4.56 (t/head/y). Therefore, raw weight (t/y) = Generation rate (t/head/y) * The numbers (heads) = 4.56 * 1,659 = 7,565 (t/y)	(1) Nguyen T. H. L. (1994) : Study on pollutants in wastes from medium-scale pig farms and application of waste treatment methods for the piggery farms, Doctoral dissertation, Nong Lam University in Ho Chi Minh City	11
	C	0	t/head/y	0	t/y	Carbon is not contained in urine.	—	-
	N	27.1	%	14.4	t/y	Nitrogen concentration under dry conditions is 27.1%, and water content of raw urine is 99.3%···(1) Therefore, nitrogen content = Raw weight (t/y) * (1-water content (%)) * Nitrogen concentration under dry conditions (%) = 7,565 (t/y) * (1-99.3/100) * 27.1/100 = 14.4 (t/y)	Nakamura M. et al. (2005) : Development of a composition database for various types of biomass, Technical Report of the National Institute for Rural Engineering, pp. 57-80	12
Number of milk cow	—	—	—	61	head	—	Interviews of VPC and Villagers	13

Generation rate of feces (milk cow)	W	8.22	t/head/y	501	t/y	Generation rate is 20-25 (kg/head/d)···(1), so the average is 22.5 (kg/head/d) ≈ 8.22 (t/head/y). Therefore, raw weight (t/y) = Generation rate (t/head/y) * Numbers (head) = 8.22 * 61 ≈ 501 (t/y)	(1) Nguyen T. H. L. (1994) : Study on pollutants in wastes from medium-scale pig farms and application of waste treatment methods for the piggery farms, Doctoral dissertation, Nong Lam University in Ho Chi Minh City	14
	C	8.55	%	9	t/y	Ratio of carbon to nitrogen is 20-25, and nitrogen concentration under dry conditions is 0.38 (%)···(1) Therefore, carbon concentration under dry conditions is 8.55 (%) in average. Water content of raw feces is 80.1 (%)···(2) Therefore, carbon content = Raw weight (t/y) * (1-water content (%)) * Carbon concentration under dry conditions (%) = 501 (t/y) * (1-80.1/100) * 8.55/100 ≈ 9 (t/y)	1) Ngo K. S. and Nguyen L. D. (1997) : Biogas production using anaerobic digestion, Book of Agriculture Publishing House, Ho Chi Minh City 2) Nakamura M. et al. (2005) : Development of a composition database for various types of biomass, Technical Report of the National Institute for Rural Engineering, pp. 57-80	15
	N	0.38	%	0.4	t/y	Nitrogen concentration under dry conditions is 0.38 (%)···(1) Water content of raw feces is 80.1 (%)···(2) Therefore, nitrogen content = Raw weight (t/y) * (1-water content (%)) * Nitrogen concentration under dry conditions (%) = 501 (t/y) * (1-80.1/100) * 0.38/100 ≈ 0.4 (t/y)	1) Ngo K. S. and Nguyen L. D. (1997) : Biogas production using anaerobic digestion, Book of Agriculture Publishing House, Ho Chi Minh City 2) Nakamura M. et al. (2005) : Development of a composition database for various types of biomass, Technical Report of the National Institute for Rural Engineering, pp. 57-80	16
Generation rate of urine (milk cow)	W	4.56	t/head/y	278	t/y	Generation rate is 10-15 (kg/head/d)···(1), so the average is 12.5 (kg/head/d) ≈ 4.56 (t/head/y). Therefore, raw weight (t/y) = Generation rate (t/head/y) * Numbers (head) = 4.56 * 61 ≈ 278 (t/y)	(1) Nguyen T. H. L. (1994) : Study on pollutants in wastes from medium-scale pig farms and application of waste treatment methods for the piggery farms, Doctoral dissertation, Nong Lam University in Ho Chi Minh City	17
	C	0	t/head/y	0	t/y	Carbon is not contained in urine.	—	—
	N	27.1	%	0.5	t/y	Nitrogen concentration under dry conditions is 27.1%, and water content of raw urine is 99.3%···(1) Therefore, nitrogen content = Raw weight (t/y) * (1-water content (%)) * Nitrogen concentration under dry conditions (%) = 278 (t/y) * (1-99.3/100) * 27.1/100 ≈ 0.5 (t/y)	(1) Nakamura M. et al. (2005) : Development of a composition database for various types of biomass, Technical Report of the National Institute for Rural Engineering, pp. 57-80	18
Number of poultry	—	—	—	8,000	head	—	Interviews of VPC and Villagers	19

Generation rate of feces (poultry)	W	0.0435	t/head/y	348	t/y	Generation rate is 0.0435 (t/head/y)···(1) Therefore, raw weight (t/y) = Generation rate (t/head/y) * Numbers (head) = 0.0435 * 8,000 = 348 (t/y)	(1) Unit for practical realization of system in Chiba pref. Bio-recycle Project ed. (2007) Prolog for construction of Agri-biomass town, pp. 22-23	20
	C	13.2	%	17	t/y	Ratio of carbon to nitrogen is 7-15, and nitrogen concentration under dry conditions is 1.2 (%)···(1) Therefore, carbon concentration under dry conditions is 13.2 (%) in average. Water content of raw feces is 63.7 (%)···(2) Therefore, carbon content = Raw weight (t/y) * (1-water content (%)) * Carbon concentration under dry conditions (%) = 348 (t/y) * (1-63.7/100) * 13.2/100 ≈ 17 (t/y)	(1) Ngo K. S. and Nguyen L. D. (1997) : Biogas production using anaerobic digestion, Book of Agriculture Publishing House, Ho Chi Minh City (2) Nakamura M. et al. (2005) : Development of a composition database for various types of biomass, Technical Report of the National Institute for Rural Engineering, pp. 57-80	21
	N	1.2	%	1.5	t/y	Nitrogen concentration under dry conditions is 1.2 (%)···(1) Water content of raw feces is 63.7 (%)···(2) Therefore, nitrogen content = Raw weight (t/y) * (1-water content (%)) * Nitrogen concentration under dry conditions (%) = 348 (t/y) * (1-63.7/100) * 1.20/100 ≈ 1.5 (t/y)	(1) Ngo K. S. and Nguyen L. D. (1997) : Biogas production using anaerobic digestion, Book of Agriculture Publishing House, Ho Chi Minh City (2) Nakamura M. et al. (2005) : Development of a composition database for various types of biomass, Technical Report of the National Institute for Rural Engineering, pp. 57-80	22
Number of buffalo	—	—	—	400	head	—	Interviews of VPC and Villagers	23
Generation rate of feces (buffalo)	W	8.22	t/head/y	3,288	t/y	Generation rate is 20-25 (kg/head/d)···(1), so the average is 22.5 (kg/head/d) ≈ 8.22 (t/head/y). Therefore, raw weight (t/y) = Generation rate (t/head/y) * Numbers (head) = 8.22 * 400 = 3,288 (t/y)	(1) Nguyen T. H. L. (1994) : Study on pollutants in wastes from medium-scale pig farms and application of waste treatment methods for the piggery farms, Doctoral dissertation, Nong Lam University in Ho Chi Minh City	24
	C	6.98	%	46	t/y	Ratio of carbon to nitrogen is 20-25 on the assumption that the value of buffalo is as same as beef, and nitrogen concentration under dry conditions 0.31 (%)···(1) Therefore, carbon concentration under dry conditions is 6.98 (%) in average. Water content of raw feces is 80.1 (%)···(2) Therefore, carbon content = Raw weight (t/y) * (1-water content (%)) * Carbon concentration under dry conditions (%) = 3,288 (t/y) * (1-80.1/100) * 6.98/100 ≈ 46 (t/y)	(1) Ngo K. S. and Nguyen L. D. (1997) : Biogas production using anaerobic digestion, Book of Agriculture Publishing House, Ho Chi Minh City (2) Nakamura M. et al. (2005) : Development of a composition database for various types of biomass, Technical Report of the National Institute for Rural Engineering, pp. 57-80	25
	N	0.31	%	2.0	t/y	Nitrogen concentration under dry conditions is 0.31 (%)···(1) water content of raw feces is 80.1 (%)···(2) Therefore, nitrogen content = Raw weight (t/y) * (1-water content (%)) * Nitrogen concentration under conditions (%) = 3,288 (t/y) * (1-80.1/100) * 0.31/100 ≈ 2.0 (t/y)	(1) Ngo K. S. and Nguyen L. D. (1997) : Biogas production using anaerobic digestion, Book of Agriculture Publishing House, Ho Chi Minh City (2) Nakamura M. et al. (2005) : Development of a composition database for various types of biomass, Technical Report of the National Institute for Rural Engineering, pp. 57-80	26

Generation rate of urine (buffalo)	W	4.56	t/head/y	1,824	t/y	Generation rate is 10-15 (kg/head/d)·(1), so the average is 12.5 (kg/head/d) ≅ 4.56 (t/head/y). Therefore, raw weight (t/y) = Generation rate (t/head/y) * Numbers (head) = 4.56 * 400 = 1,824 (t/y)	(1) Nguyen T. H. L. (1994) : Study on pollutants in wastes from medium-scale pig farms and application of waste treatment methods for the piggery farms, Doctoral dissertation, Nong Lam University in Ho Chi Minh City	27
	C	0	t/head/y	0	t/y	Carbon is not contained in urine.	—	-
	N	27.1	%	3.5	t/y	Nitrogen concentration under dry conditions is 27.1 (%), and water content of raw urine is 99.3 (%):·(1) Therefore, nitrogen content = Raw weight (t/y) * (1-water content (%)) * Nitrogen concentration under dry conditions (%) = 1,824 (t/y) * (1-99.3/100) * 27.1/100 ≅ 3.5 (t/y)	(1) Nakamura M. et al. (2005) : Development of a composition database for various types of biomass, Technical Report of the National Institute for Rural Engineering, pp. 57-80	28