BIOMASS POTENTIAL AND MATERIAL FLOW IN THE MEKONG DELTA OF VIETNAM

DANG Thanh Tu[1*], Osamu SAITO[2], Akihiro TOKAI[1] and Tohru MORIOKA[3]

[1] Division of Sustainable Energy and Environmental Engineering, Graduate School of Engineering, Osaka University.
(1-2 Yamadaoka, Suita-shi, Osaka 565-0871, Japan)
[2] Waseda Institute for Advanced Study, Waseda University.
[3] Kansai University.
* E-mail: *tu@em.see.eng.osaka-u.ac.jp; dthanhtu@yahoo.com*

Biomass is an important energy source in the Mekong Delta (MD) of Vietnam. Several studies have focused on specific areas of biomass energy, but the results to date have not been coherently and systematically integrated. Applying a material flow analysis approach, this study aimed to draw a comprehensive picture of the biomass situation and to provide future projections up to 2030. These projections take into account not only the changes in biomass material flows, but also socio-economic and environmental driving forces in the upcoming period. The results demonstrated that the theoretical biomass potential in the MD has significantly increased, from 466.8 PJ in 1996 to 637.1 PJ in 2005, and will further increase to between 500.5 and 617.7 PJ by 2030, depending on the degrees of urbanization and industrialization in the area. In terms of utilization, 70.7% of the biomass in 2006 was utilized, while the other 29.3% was wasted. Urbanization also results in a significant reduction in household biomass consumption, and therefore increases the net biomass surplus value.

Key Words : *biomass material flow, biomass utilization, rural household, Mekong Delta, Vietnam*

1. INTRODUCTION

Usable energy is a basic infrastructure requirement for the economic and social development of a country. A sufficient and sustainable energy supply is one of the decisive keys to economic growth[1)]. The economy of Vietnam has been growing significantly over the past 20 years. Total GDP in 2006 was 60.9 billion US dollars, when the real growth rate reached 8.2%. Along with the positive economic transition, the economic structure has evolved from an agriculturally-based to one that is mainly service- and manufacturing-based[2)].

In parallel with progress in economic reform and industrialization, Vietnamese primary energy demand has been growing rapidly, reaching 620kgoe per capita in 2005[3)]. It has been projected to grow continuously at a rate of 4.4% per year, mainly due to population growth, industrialization, urbanization, and economic development. Vietnam is expected to become a net-energy- importing economy beyond 2020[4)], and faces potential issues regarding energy resources and environmental concerns, such as deforestation, global warming, and air pollution[5),6),7)]. In order to cope with the coming energy shortage, and to minimize environment impacts, the Vietnamese government is making great efforts to seek and develop alternative sources, such as renewable energy, particularly biomass[8)].

Even though the share of biomass in national final energy consumption has been significantly decreasing, it still accounted for over 50% of total energy demand in 2000[9),10)]. Several studies related to biomass sources have been implemented. Nguyen[11)] concentrated on the utilization of firewood and biomass from agricultural and livestock wastes. Truong[12)] focused on its potential use for food and material supplies. Within the research frame of energy supply and demand from renewable sources, Nguyen[1)] carried out the an assessment of biomass from agriculture and forestry and its projection until 2030. The potential of biomass energy production and the conversion technologies have been considered by Nguyen[13)], Kumar[14)], and Nguyen[15)].

Although many studies have been carried out, the results have never been coherently and systematically integrated. All of the published data are at the national scale and mainly obtained from the late 1990s. The lack of a comprehensive database on current as well as future predictions of biomass sources has resulted in difficulties in identifying promising technologies and opportunities for investment. For instance, all of the information in the Vietnam Renewable Energy Action

Plan[16] refers mainly to other renewable sources, such as hydropower and solar electricity; only short sections mentioned co-generation of heat and electricity from sugarcane bagasse, which is one of several biomass sources in Vietnam.

In this context, this study herein aimed to create a comprehensive picture of the biomass situation in Vietnam, including theoretical energy potential as well as biomass flow through its end use, and to then determine the potential net surplus value (NSV) of biomass sources. By applying statistical analysis methods and reviewing the socio-economic development plans, three urbanization scenarios were developed in order to evaluate the change in biomass availability by 2030. In addition, the implications of biomass availability for environmental impact and energy production are also reviewed and discussed.

2. MATERIAL AND METHODS

(1) Study area

The Mekong Delta (MD), comprised of 13 provinces and cities, is located in the far south of Vietnam[17] (**Fig. 1**). It accounts for 13.0 and 20.7% of the national land area and population, respectively, and is one of the seven main economic regions in Vietnam (**Table 1**).

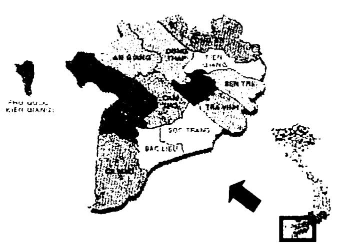

Fig. 1. Map of Vietnam and the MD.

Table 1. Socio-economic conditions of the MD[2),18)].

			MD	Vietnam
Population	Total	1,000 per	17,400.1	84,136.8
	Rural share	(%)	78.9	72.9
GDP	Total	Bill. USD	14.6	60.9
	Structure (%)	Agriculture	44.3	20.4
		Industry	22.8	41.5
		Service	32.9	38.1
Land use	Natural land	km^2	40,605.0	331,212.0
	Agri-land	(%)	63.4	28.4
	Forest-land	(%)	8.8	43.6

The MD is one of the largest agricultural regions in Vietnam, encompassing 52.0 and 50.0% of the total Vietnamese paddy and fruit cultivation areas, respectively, suppliyng 54.0 and 65.0% of the annual national rice and fruit production[18]. The share of agriculture in the total GDP of the MD in 2006 reached 44.3%, about 2.2-fold higher than the national average. However, under the economic development strategy, the agricultural share has exhibited a decreasing trend during the past ten years, with a reduction rate of 2.5%/year.

(2) Household survey

The survey, which aimed to collect basic data on household (HH) biomass energy use as well as to identify key issues and factors relating to socio-economic conditions, was conducted by direct interviews in February and March 2007. In total, eleven communes were surveyed in three rural provinces of the MD. The number of surveyed HHs was 109, 115, and 128, respectively, in Long An, Tien Giang, and An Giang provinces. The questionnaire was divided into three sections:

General information: number of people living in the HH, total agricultural area, and their estimated yearly income.

Agricultural activities: yearly production of rice and other agro-products and post-harvest biomass of HH.

Energy supply and demand: sources of energy, and the expenses for each type of energy.

(3) Estimation of the theoretical energy potential

Agricultural residues; firewood and wood residue as well as human and livestock wastes are the main biomass sources in Vietnam[9),10),19)]. The study thus concentrated on estimating the theoretical amount of energy, hereafter referred to as "energy potential" (EP), which could be acquired from these sources.

The input data for the estimation of current EP, such as annual crop production (*AP*), wood and firewood production (*WP*), and number of animals kept in the husbandry sector throughout the year (*NA*), were obtained from the national statistics[2] and databases provided by national authorities[20]. Information related to other parameters is shown in the following sections.

a) Energy potential from agricultural residue

The term "agricultural residue" is used to describe organic materials that are produced as the by-products of crop harvesting and processing. There are two main methods for the determination of residue production, i.e. using the residue-to-area ratio (RAR) or the residue-to-product ratio (*RPR, T residue/ T product*). However, confusion may result if the RAR is used, since multiple cropping is often practiced in the MD. Therefore, EP from agricultural residue (*EPar, PJ/year*) was estimated based on the RPR ratio, by **Equation1**[21),22)].

$$EPar = \sum(RPR_i \times AP_{ij} \times LHV_i \times 10^{-9}) \qquad \textbf{(1)}$$

AP_{ij}: Annual production of crop *i* in year *j (T/year)*
LHV_i: Lower heating value of residues from crop *i (MJ/T)*
i: type of crops (rice, sugarcane, maize, cassava, groundnut)

Table 2 shows the ranges of PRP_i and LHV_i, and the values used for *EPar* estimation. The ranges were obtained from available reports and studies[23),24)] in Asian countries, while the values used for *EPar* estimation came from a Vietnamese report[25)].

Table 2. PRP and LHV of agricultural residues.
Unit: RPR: T/T; LHV: 10^3MJ/T

Biomass type	Reference ranges		Value used[25)]	
	RPR	LHV	RPR	LHV
Rice husk	0.2-0.3	10.0-19.3	0.2	11.4
Rice straw	1.1-3.9	10.9-16.0	1.9	14.0
Sugarcane top & leaves	0.1-0.3	12.5-17.4	0.1	12.5
Bagasse	0.1-0.3	6.0-18.1	0.3	7.2
Maize stalk	1.0-4.3	5.3-19.7	2.0	12.5
Cassava stalk	0.1-1.0	12.5-17.5	0.3	12.5
Groundnut husk & straw	0.3-2.9	12.5-17.6	0.3	12.5

b) Energy potential from wood-based biomass

Woody biomass includes processing and field-based residues, sawdust, and HH wood wastes, as well as firewood from forests, scattered trees and fruit trees. As with agricultural residues, the EP of woody biomass (*EPwr, PJ/year*) can be estimated from the amount of biomass exploited per year and the biomass LHV.

$$EPwr_j = \sum (WP_j \times Y_w \times LHV_w \times 10^{-9}) \quad \mathbf{(2)}$$

WP_j: Amount of wood produced in year *j* *(T/year)*
Y_w: Wood residue yield *(T residue/T wood)*
LHV_w: Lower heating value of wood residues *w* *(MJ/T)*
w: Firewood, wood residues and sawdust

There were no available data directly related to the Y_w in Vietnam. In this study, they were obtained from a report on agricultural and wood residues conducted for Vietnam and other Asian countries[23)]. The $LHV_{firewood}$ and $LHV_{wood\ residue}$ values were given as 15,000MJ/T, while $LHV_{sawdust}$ was 11,600MJ/T[25)].

c) Energy potential from human and animal wastes

The potential of biogas production from human and animal waste (*EPm, PJ/year*) can be estimated by **Equation 3**[22),26)]

$$DMR_{kj} = DM_k \times NA_{kj} \times RF_k \times 365 \quad \mathbf{(3a)}$$

$$EPm = \sum (DMR_{kj} \times VS_k) \times Y_k \times LHV_b \times 10^{-9} \quad \mathbf{(3b)}$$

DMR_{kj}: Amount of dry matter (DM) recoverable from manure of animal *k* in year *j* *(kgDM/year)*
DM_k: Amount of DM in manure of animal *k* *(kgDM/head/day)*
NA_{kj}: Number of animals *k* in year *j* *(head/year)*
RF_k: Manure recoverable fraction of animal *k* *(%)*
365: Operation time in a year *(365 days)*
VS_k: Fraction of volatile solid in DM of animal *k* *(kgVS/kgDM)*
Y_k: Biogas yield of animal *k* *(Nm3/kg VS)*
LHV_b: Lower heating value of biogas *(MJ/m3)*
k: type of animal (cow, buffalo, pig, sheep, goat, poultry)

Regarding the LHV_b, values varying from 18 to 27MJ/m^3, have been previously reported[27),28),29),30)]. This study used the most common value found in the scientific literature, of 20.0MJ/m^3, for estimation.

There were no available data on the characteristics of human waste and animal manure in Vietnam, so data from Asian countries, as reported by Bhattacharya's[21)], were utilized (**Table 3**).

Table 3: Characteristics of animal manure[22)].

	RF	DM	VS	Y
Cow	0.50	2.86	0.93	0.20
Buffalo	0.50	2.53	0.80	0.30
Pig	0.23	0.66	0.89	0.31
Sheep & Goat	0.33	0.44	0.76	0.31
Poultry	1.00	0.05	0.43	0.20
Human waste	1.00	0.09	0.67	0.20

(4) Scenario development and analysis

Urbanization has been creating various impacts on the national economy, society and the environment[31)]. It is also creating impacts on the energy supply and demand[32)] situation. The effects of these impacts on future biomass production and consumption over a relatively long time-scale were examined through three scenarios, with the following assumptions:

- The urban population growth rate, which refers to the growth in the number of urban residents in the studied areas, increased from 1.1 to 3.9% per annum during the last decade. The selected growth rates for scenario development in low- (SC1), medium- (SC2), and high-urbanization (SC3)scenarios were 1.0, 2.5, and 4.0% per year, repectively. By 2030, the share of urban residents in the total MD population will reach 41.5% in SC3, almost the same as the average rate of Vietnam as a whole as projected by the UN[33)].

- The population growth rate of Vietnam was estimated to be the same as the UN projection[33)], and the MD still accounts for 21% of the total national population.

- The land under urban development is expected to reach 80m^2/capita by 2010 and then stabilize at 100m^2/capita from 2020 on[32)]. The new urban construction land will be mainly from converted rice cultivation areas.

Table 4 summarizes the main assumptions for scenario development. The sub-assumptions, which directly relate to the changes in supply side and/or demand side, are described in the following sections.

a) Changes in supply side

Agriculture sector

The changes in agricultural production *(Cr_{ij}, T/year)* can be estimated from historical trends in harvested area (*Ar_{ij}, ha*) and product yield (*Pr_{ij}, T/ha/year*), while RPR is assumed to be constant[34)] (**Equation 4**).

$$Cr_{ij} = Ar_{ij} \times \mathrm{Pr}_{ij} \quad \mathbf{(4)}$$

Table 4. Main assumptions for scenario development.

		Unit	2005	2010			2020			2030		
				SC1	SC2	SC3	SC1	SC2	SC3	SC1	SC2	SC3
Urban population growth rate		%/year		1.0	2.5	4.0	1.0	2.5	4.0	1.0	2.5	4.0
MD population		10^6 person	17.3	19.1	19.1	19.1	21.3	21.3	21.3	23.2	23.2	23.2
- Urban population			3.6	3.8	4.1	4.4	4.2	5.2	6.5	4.6	6.7	9.6
- Rural population			13.7	15.3	15.0	14.7	17.1	16.1	14.8	18.6	16.5	17.6
Land use change	Urban land use	10^3ha	288.5	303.2	326.4	351.0	418.7	522.3	649.4	462.5	668.6	961.3
	Forestry land		355.1	422.6	422.6	422.6	499.6	499.6	499.6	594.2	594.2	594.2
	Agriculture land		3,089.3	3,007.1	2,983.9	2,959.3	2,814.6	2,711.0	2,583.8	2,676.2	2,470.1	2,177.4

Paddy production: Intensive rice production has created significant productivity improvements at an average annual rate of 1.8% from 1995 to 2006 and is projected to remain at 1.8% until 2010. From 2010, the rate will decrease to 1.0% and then remain constant at 6.1T/ha from 2020 onward.

Sugar production: The industry has been faced with challenges from illegally imported products, creating a 2.7% reduction in cultivated area per year during the 1995-2006 periods. It will continue to decline at a the lower rate of 1.3% until 2010. Governmental efforts as well as the increase in world market demand for sugar are expected to stabilize the Vietnamese sugar industry. The cultivated area is then projected to increase by 0.8% per year from 2010 onward. Although sugar cultivation productivity increased by 2.8% annually from 1995 to 2006, it was still lower than in other Asian countries[35]. Cane productivity is projected to grow continuously at the same rate, due to the integration of seed improvement and intensive cultivation.

Other crop production: Maize, groundnut, and cassava are minor products, covering 0.7, 0.6, and 0.3% of the total crop area, respectively. In the future, due to the significant growth of the animal husbandry sector, maize and cassava area will increase by 7.2 and 4.0%, while groundnut area will be reduced by 2.2%. The annual productivity of maize, cassava, and groundnut will increase by 1.5, 2.0 and 1.0%, respectively.

Fruit cultivation: The cultivation areas rapidly increased from 177,000 to 331,400 hectares (ha) from 1995 to 2006 with an average annual growth rate of 8.6%[2),36)]. However, market fluctuations and the impact of the urbanization process will decrease the growth rate of the fruit cultivation sub-sector to 3.6% from 2005, and then to 2.2% after 2010.

Forestry sector

Growing pressure on firewood, construction material and rice cultivation have led to rapid degradation in forest areas[37)]. Several protection policies have been implemented since 1999, leading to the recovery of forest areas, from 264,400ha in 1999 to 304,100ha in 2007[2)]. This increasing trend, which is mainly based on the development of production forests, is expected to continue at a rate of 4.8, 2.6, and 2.5% until 2010, 2020, and 2030, respectively. The area of protection and special use forests will not change until 2030.

Animal husbandry sector

Population of major livestock has been increasing in accordance with the rapid increase in meat demand. However, the Asian share of world meat production has been relatively low when compared to its animal population[38)]. The husbandry population (*Pop, head/year*) was predicted by the following formula (**Equation 5**) and assumptions:

$$Pop_{kj} = \alpha_k + \beta_k \times (C_{kj} \times P_j) / MP_k \qquad (5)$$

α_k, β_k: Constants for animal k

C_{kj}: Consumption of meat k in year j *(kg/person/year)*

P_j: Human population in year j *(person)*

MP_k: Average meat production of animal k *(kg/head)*

- Domestic meat demand will continuously be satisfied by local supply.

- By 2030, 70.0% of the pork meat production will be used for domestic consumption and 30.0% exported.

- To boost pig meat export and reduce the reliance on imported milk, swine and cattle will be the prioritized animals for husbandry activity[39)]. Poultry, which currently provides eggs and meat at rates 1.8 and 1.2 times higher than demand, respectively, will be maintained at the same population level.

In 2003, per-capita meat consumption in the MD was 31.0kg, 20.0% lower than the East Asian average in 1999[40)] with the shares in total consumption of pork, beef, buffalo, and poultry at 86.0, 3.3, 0.3, and 10.5%, respectively. By 2030, it is expected to be the same as the East Asian region, at 58.5kg per capita[41)]. The distribution of meat types will change, with pork, beef, buffalo, and poultry consumption at 52.1, 1.4, 0.5 and 4.6kg/capita/year.

Even if milk production per capita increased 10% annually to reach 2.9kg/year by 2005, the production would still be lower than other countries[40)]. This is expected to reach 17.8kg/person per year, the same level as East Asian countries, by 2030. With the average milk yield of dairy cows at 1,500kg/year, the MD will have 260,000 dairy heads by 2030.

b) Change in demand side

Changes in biomass use in the residential sector

The impact of urbanization and industrialization on the rural residential sector, especially on the situation of biomass utilization, can be assessed by the change in socio-economic conditions[42]. Multiple regression analysis was used to identify factors that influenced the share of biomass sources for cooking in rural HHs (the response variable). The potential predictors were HH income, per-capita income, the share of agricultural income in total income, and HH size, which were obtained from the rural HH survey in 2007. Due to the significant correlation between some predictors, only independent variables (per-capita income and HH size) were chosen as variables for the regression equation.

The future projection of per-capita income (IC_j, 10^6 *VND/capita/year*) was estimated by **Equation 6**.

$$IC_j = a + b \times GDP_{2006} \times (1 + \varepsilon_j)^{\Delta y} \quad (6)$$

a, b: Constants for estimating IC_j from per-capita GDP

GDP_j: per-capita GDP of MD in year *j (VND/capita/year)*

ε_j: GDP growth rate in year *j (%)*. There were no available data directly related to ε in the MD. The study used national data from the past five years for projection. The ε_{2010} of SC1 and SC3 were taken as the national mean and maximum values, while that of SC2 was the average of the other two scenarios. From 2010 onward, the ε will gradually decrease, reaching 7.0, 7.5 and 8.0 in SC1, SC2 and SC3, respectively, by 2030.

Regarding HH size (μ_j, *person/HH)*, we assumed that the μ_{2030} will not change in SC1, while in SC3, it will be reduced to 3.5 persons per HH, the same as national average by 2030, as predicted from the population proportion in each age group by the formula of *Jennings et. al*[43]. The constants for projection of average HH size at the national scale were estimated by a least-squares approximation method applied to national census data from 1999, 2004, 2005 and 2006[2]. The μ_j in SC2 was taken as the median between SC1 and SC3.

Small-scale industrial sector

Sugarcane mills: The existing co-generation plants in Vietnamese sugar mills use around 7kg bagasse to produce 1kWh of electricity, while an efficient plant requires only 3kg[44],[45]. Presently, the mills require 20-60kWh of electricity and 0.5-0.6 tons of steam to process 1 ton of cane. However, if high-pressure, superheated steam boilers and high-efficiency turbo generators are used, the process requires only 20kWh of electricity and 0.4 ton of steam for every ton of cane[46]. We assumed that different technologies would be invested to reduce energy consumption in the sugarcane industry. The type of new technologies invested in will be decided based on the level of economic development, which corresponds to the assumptions of the scenarios (SC1 to SC3). The electricity consumption per ton of cane will decrease to 40, 30 and 20kWh, respectively, in SC1, SC2 and SC3. While the bagasse consumption to produce 1kWh of electricity will not change in SC1, it will be reduced to 5kg in SC2 and 3kg in SC3, for a consumption in SC1, SC2, and SC3 of 280, 150 and 60kg bagasse per ton of cane, respectively.

Traditional brick kilns: As promulgated policy, the small- scale brick kilns will be phased out by 2020 due to the serious environmental damages. The study also assumed that 50% of the kilns will be closed by 2010 and 100% by 2020.

Rice dryings: The equipment for rice dryings will remain the same as in the present, with rice husk consumption at 60 kg per ton of rice.

3. RESULTS

(1) Current trends in biomass energy potential, utilization, and biomass material flows

a) Trends in biomass energy potential

Agricultural residues

In terms of EP, agricultural biomass has rapidly increased, from 422.3PJ in 1996 to 582.7PJ in 2005, with an average annual growth rate of 3.3%. The trend was mainly driven by the increase in rice productivity and cultivation area. In 2006, agricultural biomass decreased by 5.3%, to 551.8PJ, due to the spread of pestilent insects and economic transformation, which led to a reduction in both productivity (4.0%) and paddy field area (1.0%).

In terms of composition, agricultural biomass is driven mainly by rice husk and straw, which compose 7.9 and 87.7%, respectively, of the total *EPar*. Cane top and bagasse from sugar cultivation and processing provide only 1.2 and 2.4%; the other 0.8% comes from groundnut, maize, and cassava.

Firewood and wood residues

The *EPwr* in the MD increased from 40.8PJ in 1996 to 49.4PJ by 2006, with an annual growth rate of 1.9%. In terms of structure, the wood-processing industry, plantation forest, and fruit trees are the main providers, with shares of 33.1, 26.9, and 16.1%, respectively, in total woody biomass supplied. While wood waste from the HH sector comprises 9.0% of *EPwr*, that from scattered trees, which refers to individual trees that are planted mainly in home gardens as well as along farm boundaries, roadsides, and canal banks[1], account for 5.8%. Natural forests and bare forests supplied 3.2 and 2.1% of total *EPwr*, respectively.

Human waste and husbandry manures

The *EPm* has increased by 3.4% per year during the last decade, from 3.8 PJ in 1996 to 5.3PJ in 2006. In terms of structure, the major *EPm* providers are humans (33.4%), poultry (27.5%), and pigs (22.2%). Cattle, buffalo, and other animals are considered minor producers, providing 13.6, 3.1, and 0.3% of the total potential, respectively. The average losses of biomass due to non-recoverable animal manures during the period of 1996-2006 were 775,400 tons per year (equivalent to 2.6 PJ).

Total biomass energy potential

Total MD EP, which includes the estimated *EPar*, *EPwr* and *EPm*, has rapidly increased from 466.8PJ in 1996 to 637.1PJ in 2005, with an average annual growth rate of 3.2%. In 2006, it decreased by 4.8%, due to a significant reduction in agricultural yields. In terms of structure, agricultural residues have been dominated, providing 91.4% of total EP, while the share of human and husbandry manures and woody biomass are 0.8 and 7.8%, respectively (**Fig. 2**).

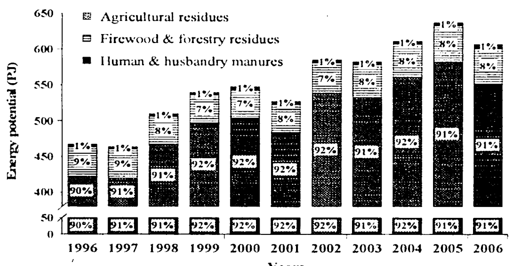

Fig. 2. Theoretical biomass EP in the MD.

b) Biomass utilization

Wood fuel and agricultural residues are widely used as energy sources in Vietnam, especially in the residential sector[9),11),12),14)]. It is currently treated as a non-commercial energy source; collected and used locally. The use of biomass for energy production in a commercial sense has not received the attention of energy planners as have other sources, such as hydro-electricity and solar power. Of the current utilized biomass, 77.4% is used for the HH sector, while 22.6% is used for the industrial and craft sector[47)].

Household biomass consumption

The HH biomass consumption situation was obtained from the results of our survey in 2007[42)].

Biomass sources for energy supply

Although quantities and structures of HH energy consumption vary from province to province, firewood and rice husk are still considered to be the most important energy sources for rural residents. Of the surveyed HHs, 93.0 used firewood and 18.5% used rice husk for cooking, contributing 73.8 and 10.2% of the total energy use. Converted to calorific value, the total firewood and rice husk used for cooking in the MD is equivalent to 67.0 and 7.6PJ.

The survey results also indicated that 2.6% of HHs own small-scale biogas systems, which convert 40.4% of recoverable husbandry manures to biogas for cooking. Assuming that the amount of biogas produced is fitted with the HH cooking demand, at least 2.1PJ of energy can be derived from animal manure for energy purposes.

Biomass sources for other purposes

The HHs in MD, in comparison to the other regions of Vietnam, does not use much agricultural residue for energy purpose. Estimated results demonstrated that rice straw provided 87.7% of *EPar* (or 79.8% of total biomass EP), of which, 6.1% was collected for fungi production, animal feeding, and fruit dunnage. Another 61.9% (21.4 million tons - MT) was burned in the field to produce fertilizer, which was considered as a form of material supply in this study.

In the agro-processing enterprises, 100% of rice bran and 82.0% of cassava bagasse were used for animal feed. The entire part of the rice straw (32.0%), cassava bagasse (18.0%), and sugarcane bagasse (20.0%), sugarcane top, as well as the wastes from corn and groundnut cultivation were left at farms and/or openly dumped as municipal solid waste.

Concerning livestock manures, only a relatively small part (3.6% of recoverable) was re-used to feed fish and fertilize fields and gardens. The entire part, including 56.1% of recoverable manures (3.0PJ) and the whole of the non-recoverable amount (equivalent to 5.6PJ of energy), was directly disposed into streams or rivers, posing a serious environmental threat.

Biomass consumption in the industrial sector

In addition to HH uses, rice husk is also the preferred fuel for industrial activities, such as rice drying or brick making. A third of rice production in the MD (equal to 6.1MT/year) is harvested during the rainy season and must be dried by a mechanical system, which uses rice husk as an energy source[25)]. Assuming that husk consumption for drying was 60kg/ton of rice[48)], 363,900 tons of husks were needed for rice drying every year. Brick factories, which utilized half of the MD rice husk (equal to 1.9MT) as an energy supply for traditional kilns, were also main consumers of husk[49)].

Co-generation systems are widely applied in the sugar-processing factories of Vietnam to cover part of their energy demand. Some large-scale factories also have systems to produce alcohol or biogas from wastes. It has been reported that 80.0% of bagasse (equal to 1.3MT) has been used for energy[35)]. The surplus, up to 20.0%, is used for other purposes, such as making paper and board, but most is wasted[45),50)].

c) Current biomass material flow

The biomass energy flow estimation is normally made from data centered on the three main areas of biomass production, namely agriculture, livestock, and forestry[51]. In this study, the flow was established using the EP in 2006 and present utilization levels of the three main biomass sources (**Fig. 3**). The flow of biomass in all forms was followed from the source of production through to its end use and categorized into end-use group, such as energy supply, material supply and wastes, therefore, providing a clear overview on the situation of biomass energy in the study area. The term "end-use" in this paper means the primary energy demand, both in residential and industrial sectors.

Current biomass material flows at the sector-level

Regarding agricultural biomass, 42.9 and 329.2PJ were used for energy and material supply, respectively, while 179.9PJ (32.6%) was wasted.

In 2006, only 2.1 and 0.2PJ of biomass sources from human waste and husbandry manures were used for energy and material supply. The major part consisting 3.0PJ from recoverable and 5.6PJ from non-recoverable manures, was directly discharged to rivers and other water channels[52].

For woody biomass, 3.1MT of firewood and 159.0 thousand tons sawdust, equivalent to 49.3PJ of energy, were produced in 2006. The estimated *EPwr*, which excludes uncountable sources, such as gardens or illegal forest exploitation as well as illegal wood imports, was 35.8% lower than the total firewood demand in the residential sector. Assuming that uncountable woody biomass was used to compensate for the firewood lack in rural HHs of the MD, 17.7PJ of energy were derived from such sources in 2006.

Overall picture of biomass material flow

Results of biomass material analysis also show the aggregated level of biomass used in the MD, with 62.9% (381.3PJ) utilized in the HH sector and 9.9% (60.0PJ) in the industrial sector. The remaining 27.2% (165.2PJ) was wasted or used for other purposes. For total biomass, 52.8% and 17.9% was utilized for material and energy supply, respectively, while 29.3% was wasted. In the material supply group, 91.0% (299.6PJ) was on-site open-burned for ash production, which was also due to the difficulties in stringing straw and moving it out of the fields. The utilization for energy supply accounted for the smallest end-use share, of which 68.4% (76.7PJ) was used for HH cooking, 19.4% (21.8PJ) for brick making, 8.4% (9.4PJ) for electricity generation in sugarcane factories, and the last 3.7% for rice drying.

(2) Change of net surplus value

The term "net surplus value" (NSV) is used to describe the gap between the supply potential of primary biomass energy and its demand in the MD.

a) Changes in biomass supply potential

Low-urbanization scenario (SC1)

In SC1, the ratio of urban population will increase 1.0% annually, meaning that the excess urban construction demands in 2010, 2020, and 2030 will be 14.7, 130.2, and 174.0 thousand ha.

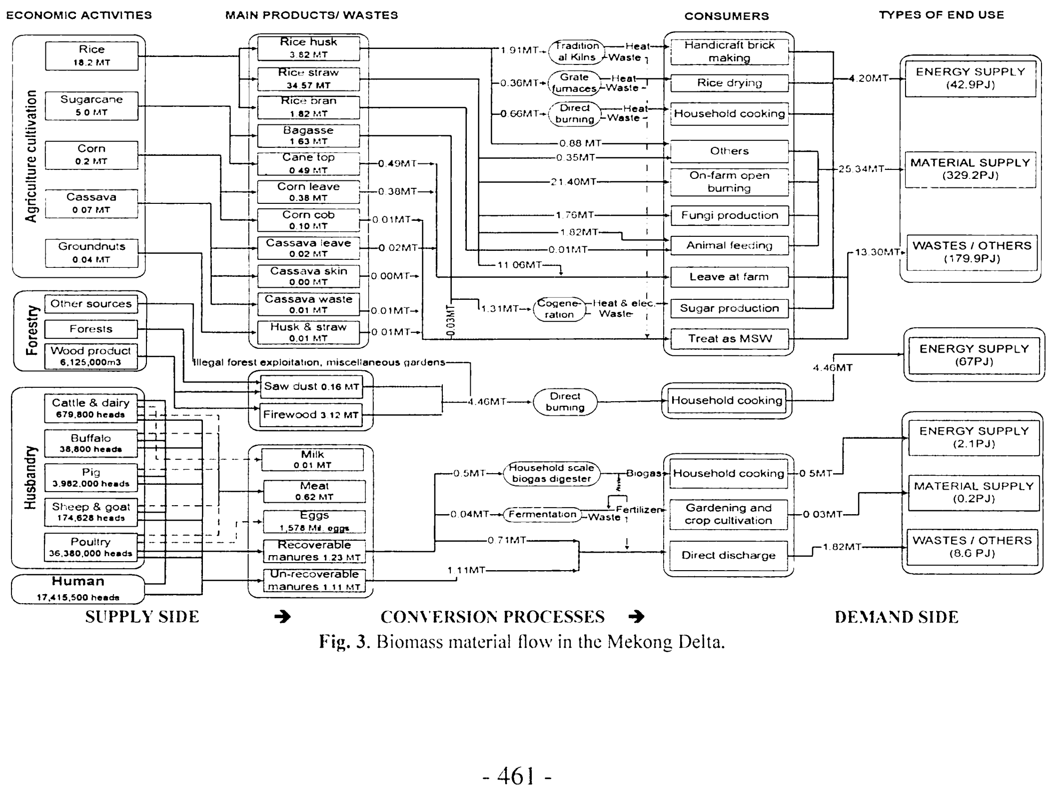

Fig. 3. Biomass material flow in the Mekong Delta.

Integrated with other land use changes, rice cultivation areas will be reduced by 1.6% annually and reach 2.6million ha by 2030. Total biomass EP will increase by 1.7% until 2010. From 2010 onward, a decreasing trend will be seen, with a total reduction of 10.7% from 2010 to 2030 (**Table 5**).

Medium-urbanization scenario (SC2)

The SC2 was developed with an annual urban population growth rate of 2.5%, in which, on average, 15.2 thousand ha of agricultural lands will be converted into urban space every year. The rice cultivation areas will decrease by 2.1% annually in the region, reaching 2.2 million ha by 2030. Biomass EP will increase until 2010, with an average annual growth rate of 1.5%. After 2010, it will decrease by 0.9% per year, with a supply potential in 2030 of 569.2PJ (**Table 5**).

High-urbanization scenario (SC3)

With urban population growth rates of 4.0%, annually, 26,900 ha of agriculture land will be converted into urban areas. Rice cultivation areas will be reduced by 3.0% per year and reach 1.8 million ha by 2030. In this scenario, biomass EP increases and reaches 682.0PJ by 2010, but it is projected to have a reduction rate of 1.5% annually after 2010 (**Table 5**).

b)Changes in biomass demand

Residential sector

Factors influencing biomass use

Biomass utilization in the MD is closely related to HH size and per-capita income. There is a significant negative correlation between per capita income and the share of biomass in total energy consumption for cooking (R=-0.758, P=0.000) (**Fig.4**). HHs with higher income have a tendency to use less biomass than others. In terms of HH size, the larger HH size will consume more biomass energy for cooking (R=0.224, P=0.019) (**Fig.4**).

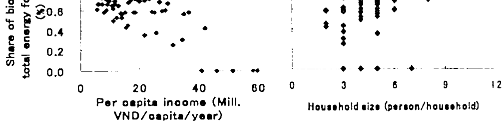

Fig.4. Correlation between per-capita income, HH size and biomass use.

Results of multiple regressions demonstrated the significant correlation between per-capita income, HH size and biomass used for cooking (multiple R=0.77, R^2=59.30%, R_{adj}^2=58.54%, P=0.000). Due to the significant increase of per capita income (6.0-7.0% per annum) and the reduction of HH size (0.0-1.0% annually), the share of biomass in total energy used for cooking will decrease from 84.0% in 2005 to 39.6-52.2% in 2030. The average reduction rate over the projection periods will be 1.9, 2.4, and 3.0% per annum, respectively, in SC1, SC2, and SC3.

Urbanization and biomass use

The change in HH structure, mainly driven by population growth and internal migration, also impacts biomass utilization in rural HHs of the MD. The increasing commercialization of agriculture and the replacement of labor with capital inputs have been releasing the rural workforce, and prompting migration in search of better economic and income opportunities[53]. This internal migration, especially the migrants within the region, results in a significant increase of HH numbers. Depending on the urban population growth rate, the number of HHs in SC1, SC2, and SC3 will increase by 32.2, 49.4, and 71.8%, respectively, over the projection period, from 3.9 million in 2005 to 5.1, 5.8, and 6.7million, respectively, in 2030. Average biomass demands in SC1, SC2, and SC3 over the 2005-2030 period will respectively decrease by 39.2, 52.4, and 66.6%, from 464.4 to 282.3, 221.1, and 154.9kgoe/HH/year. Total biomass demand will decrease from 81.4PJ in 2005 to 65.4, 57.9, and 46.6PJ by 2030 in SC1, SC2 and SC3, respectively; equivalent to 19.7, 28.9, and 42.7% reductions over the projection period (**Table 5**).

Industrial sectors

Biomass demand in industrial sectors will reduce significantly in all 3 scenarios (**Table 5**). The highest reduction is found in SC3, with a total reduction in projection period of 73.3%. The reduction in SC2 and SC1 are 54.4 and 30.3%.

c) NSV and its driving forces

In terms of supply availability, only a part of the husbandry and agricultural residues can be used as energy[1]. The results of the material flow analysis indicated that 67.4% of agricultural biomass is used for energy and material supply, while the other 32.6% are unused. We expected that part of the straw, which was on-site open-burned to produce fertilizers and was considered as a form of material supply in this paper, can be used for energy supply. The amount of agricultural residues that can be used for energy supply would therefore reach 50.0%, the same as the value proposed by Khanh[1]. Our material flow pointed out that in 2006, 40.3 and 3.7% of recoverable manures were utilized for biogas and fertilizer production, respectively, while the other 56.0% was directly discharged into river and channels. In this study, we assumed that all of the wasted manures would be used for biogas production, meaning that 96.3% of recoverable manures could be used for energy production. Fig.5 shows the NSV in the MD over the 2005-2030 periods.

Table 5. Projection of future theoretical biomass supply and demand *(Unit: PJ)*.

		2005	2010			2020			2030		
			SC1	SC2	SC3	SC1	SC2	SC3	SC1	SC2	SC3
Biomass supply	Agricultural residues	582.7	639.4	633.8	627.9	620.1	592.7	559.0	537.8	483.2	405.6
	Woody biomass	49.6	46.4	47.1	47.8	58.4	61.1	65.4	69.9	76.0	84.8
	Human and husbandry wastes	4.8	6.3	8.0	10.0	6.3	8.0	10.0	6.3	8.0	10.0
	Total biomass supply ability	637.1	692.0	687.2	682.0	686.6	662.2	632.4	617.7	569.2	500.5
Biomass demand	Residential sector	81.4	82.8	80.9	78.9	81.4	78.6	74.4	65.4	57.9	46.6
	Industrial sector	44.2	35.3	30.5	27.2	27.7	20.4	15.1	27.2	15.1	11.8
	Total biomass demand	125.6	118.1	111.4	106.1	109.1	99.0	89.5	96.2	78.0	58.5

Table 6. Summary of HH number, GDP per capita, HH biomass demand and NSV.

	2005	2010			2020			2030		
		SC1	SC2	SC3	SC1	SC2	SC3	SC1	SC2	SC3
Number of HH *(10^6 HH)*	3.9	4.2	4.2	4.2	4.7	5.0	5.4	5.1	5.8	6.7
GDP per capita *(10^6 VND/cap./year)*	8.1	10.7	11.0	11.3	19.3	20.7	22.2	35.0	39.3	44.2
Biomass demand *(kgoe/HH/year)*	464.4	434.3	424.2	413.6	381.8	347.1	308.4	282.3	221.1	154.9
Net surplus value *(PJ/year)*	219.8	254.1	258.6	561.7	267.1	266.6	163.1	252.2	249.3	238.8

The NSV in the MD will slightly increase at average growth rate of 1.2-1.3% per annum due to the advantages of agriculture production until 2020. However, under the effects of urbanization, the NSV will decrease by 5.6, 6.5 and 9.2%, respectively, in SC1, SC2 and SC3 during the 2020-2030 period.

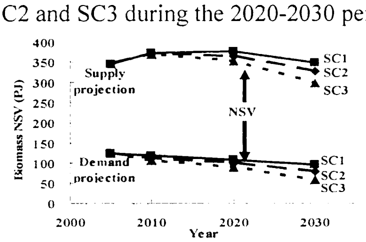

Fig. 5. Balance of biomass energy supply – demand.

The previous sections separately showed the inter-relation between theoretical biomass supply and demand versus urbanization and economic development. To create the overall view of NSV as well as examine the changing dynamics, these factors must be integrated into the analysis (**Table 6**). The results show that high urbanization, which results in a significant increase in HH number and GDP per capita, will lead to lower biomass demand. In contrast, the lower urbanization and lower GDP per capita will lead to a higher share of biomass in total HH cooking energy. In terms of total theoretical supply and demand, the higher urbanization will lead to the lower supply availability, and therefore result in a lower biomass NSV.

4. DISCUSSION

(1) Biomass production in the MD

The 606.5 PJ of energy produced from agriculture, forestry, and livestock can be regarded as the total EP in the MD by 2006. If per-capita energy consumption is 620 kgoe/year, the biomass EP in the MD was 23.6% higher than demand. Among the sources, agricultural residues, which have the same contribution to total biomass EP as woody biomass at the national scale[1], are the most important source in the MD, comprising 91.4% of EP during the period of 1996-2006, and will stand at over 81.0-87.1% until 2030 (**Fig. 2** and **Table 5**). The difference between our study and Khanh's resutls[1] can be explained by the significant difference in land use situations, in which the share of forestry in total natural land in the MD and the whole country are 8.8 and 43.6%.

Different projection approaches produce varying results for biomass projection. In 2005, Nguyen[1] projected total biomass potential in Vietnam, but the relationships between biomass production and other social-economic conditions were not identified. Those relations were examined in our study through the application of three urbanization scenarios. The results showed that if urban population growth rate vary from 1.0 to 4.0%, agricultural land in the MD would decrease by 13.4-29.5%. With a land circulation ratio of 1.5 times/year[2], total rice cultivation land will decrease by 33.4-53.0%, and paddy production will be reduced by 19.6-43.2% during the 2005-2030 period. Even so, due to the reduction of per-capita rice demand as well as the diminishment of national rice export (from 6.6 to 3.3MT over 2007-2020) [54], the area would have a surplus of 2.0MT of rice for domestic consumption in the other regions. The total biomass potential would decrease by only 3.0-21.4% due to the increase of biomass sources from husbandry and forestry sectors.

(2) Utilization of biomass energy

As shown in **Fig. 3**, 70.7% of biomass produced in the MD has been utilized for material and energy supply. Among material supply groups, 91.0% was used for on-site open burning to produce fertilizer, which has been recognized as a key driver of global climate change[55),56),57)]. The work done on rice straw[58)] concluded that the economic value of the rice straw as a fertilizer is significantly higher than that for energy use, and the supply potential of straw for a specific briquette plant was negligible. Over the years, the situation has changed somewhat and present trends suggest that priority should be given to generating energy from biomass wastes. The emissions balance shows that straw utilization for power production is a "cleaner" solution than on-site open burning for all pollutants tracked[59)]. Using rice straw for power production is viable and rational in terms of energetic and environmental impact and very nearly economically feasible in the current energy market. Up until now, many suitable materials and compounds can be substituted for rice straw in its various current uses. If sufficient subsidies are granted for substitution activities, and energy producers pay a high price for rice straw, it can become one of the most valuable feedstocks for energy production in the MD.

Regarding energy supply group, 59.8% of the utilized biomass came from firewood and wood residues. The woody biomass supply ability, excluding uncountable sources such as illegal forest exploitation, was 35.8% lower than firewood consumption in 2006. Evidence demonstrated that the *Malaleuca* forest in the MD is capable of sustaining only 30,000 - 40,000 m^3 per year, but supplied three times that amount in 1993 to satisfy the fuel wood demand. Heavy firewood exploitation plus rapid expansion of coastal shrimp aquaculture have resulted in destruction of more than half of the forest existing in 1982[60)].

In terms of future predictions, higher urbanization as well as higher income will lead to lower biomass consumption in the residential sector[61)]. The change in size and number of HHs also affects fuel consumption patterns, since smaller HHs tend to favor modern fuels for cooking, such as LPG or electricity. However, the current electricity price and supply availability have limited the HH energy transition in the MD. Electricity end-users often pay more than the official tariff and even more than marginal cost, because of the common practice of electricity resale in rural areas of the MD[62)]. Rural HHs therefore prefer cheaper fuel sources for cooking. The situation will change if the energy supply and national infrastructure is improved.

(3) Relation between NSV and the efficiency of biomass conversion systems

In the previous sections, the study focused on estimating the trend of biomass supply, the changes in biomass demand and identifying the theoretical NSV in the MD, which did not take into account the efficiency of biomass conversion systems. However, the efficiency of biomass conversion systems in Vietnam is still very low, about 8-12% for rice husk and 10-17% for firewood[63)]. This means that, by 2005, the actual biomass NSV in the MD could only reach 10-12% of the theoretical NSV value, which demonstrated in **Fig. 5** and **Table 6**. Improvements in efficiency may create significant influences on the actual NSV situation in the MD.

Assuming that new technologies such as application of improved cook stoves and small scale gasifier systems would be introduced to both industrial and residential sectors by 2030, the average conversion efficiency would improve up to 20-25%[1), 64)]. The actual NSV in the MD would reach 60-70PJ per year, approximately equivalent to 30% of the total theoretical NSV in **Fig. 5** and **Table 6**.

(4) NSV and its implications for environmental protection and energy production

Approximately 80.0% of NSV in 2030 will come from rice residues such as rice husk and rice straw. Due to the low-density characteristic of rice residues (60-180 kg/m^3), it is very difficult to store and handle also leading to a high transportation cost. Due to the limited storage spaces, large amounts of residue are dumped in the branches of the Mekong River or burned in open piles, producing air and water pollution, and disturbing fish habitat[65)]. Moreover, the rice husk that is stored in open spaces may result in particulate emission, and damage air quality[11)].

Using agricultural residues as a fuel in the energy sector, since they are a carbon-neutral fuel, can be a way of offsetting carbon dioxide emissions from the energy supply system, and help to solve their disposal problems[62)]. In 2002, half of the electricity in Vietnam was being generated by hydropower. This share will be reduced to 26.3% by 2030 due to the significant increase in electricity demand and the limitation of hydropower production. A fossil-fuel based economy will lead to the increase of per-capita CO_2 emission, from 0.7 to 2.8tons/capita by 2030[4)]. The application of biomass for electricity generation can significantly contribute to mitigation of GHG emission in this area. From the economic point of view, the benefits are different between plant scales. The economic viability of large-scale plants can be reached without revenues from ash sale of Clean Developmet Mechanism support, while the profitability at smaller scales is influenced by whether the electricity is sold directly to the rice mills or to the national grid[62)].

The significant reduction in supply availability and a stable biomass demand may result in resource shortages in the coming decades. Transportation cost is also one of the barriers for expanding the application of biomass due to the scattered and low-density characteristic of agricultural residues. Therefore, decisions in selecting technology, spatial scale, and location should be carefully considered in order to maximize the efficiency of resource utilization and minimize the social and environmental impacts.

5. CONCLUSIONS

By applying a material flow analysis for the first time to the MD, this study revealed a comprehensive picture of biomass sources in the MD, including supply potential, biomass demand, and NSV under three urbanization scenarios until 2030.

In general, the MD possesees abundant sources of biomass, mainly driven by agricultural production and land-use conditions. The biomass EP has significantly increased, from 466.8PJ in 1996 to 637.1PJ in 2005. Dependent on the future urbanization and industrialization in the area, it is projected to be between 500.5 and 617.7PJ in 2030.

In terms of biomass utilization, our results showed that 70.7% of biomass is currently utilized, while the other 29.3% is unused. Even so, most of the utilized biomass, especially rice residues, is often handled and comsumed in an inefficient manner (burned in the field or directly burned for heat using low-efficiency kilns), resuting serious environmental problems[11),65)].

The policy toward economic transformation and urbanization will create a reduction trend in biomass demand in the industrial and HH sectors. From 2005 to 2030, total biomass demand in industrial sector will be reduced in low-, medium- and high- urbanization scenarios. Biomass demand per HH will significantly decrease in all three scenarios, and result in a 19.7-42.7% reduction in total biomass demand in the residential sector. However, the limitation of supply potential will result in the reduction of biomass NSV from 2020 onward. (**Fig. 5, Table 6**).

The concept of agricultural residues as a fuel for power generation might be a solution to reduce the burden of economic growth and urbanization on the energy sector, the dependency on fossil fuel, and the negative environmental impacts. The appropriate selection of installation sites, which can help to reduce the transportation cost of feedstock and energy, will also be a key toward the successful implementation of such projects. Our study has represented the availability of each biomass source in the MD as a database on the supply side. Depending on the availability of input data, the same calculation can also be applied to examine the potential in other regions and/or at other scales, such as provincial or community levels. If sufficient data on energy consumption and projections are provided, it will become a complex and useful database for policy makers and investors interested in the growth of sustainable energy production.

ACKNOWLEDGEMENT:
The HH survey was carried out with the financial support of the Mentoring Program (Osaka University) - fiscal year 2007. We would like to thank participating farmers and local officers for their assistance and cooperation during the HH survey.

REFERENCES

1) Nguyen QK: Long term optimization of energy supply and demand in Vietnam with special reference to the potential of renewable energy. Dissertation. University of Oldenburg, 2005.
2) General Statistic Office of Vietnam (GSO). National statistical data 2006. Available at: http://www.gso.gov.vn.
3) IEA: Selected 2005 energy indicators for Vietnam. Available at: http://www.iea.org/Textbase/stats/indicators.asp?COUNTRY_CODE=VN.
4) APEC: APEC Energy demand and supply outlook 2006, Energy at the crossroads. Japan 2006, available at http://www.ieej.or.jp/aperc.
5) Nguyen AT: Energy and environmental issues in Vietnam. Natural Resources Forum Vol. 21. No. 3, pp. 201-207, 1997.
6) Dincer I: Environmental impact of energy. Energy Policy Vol. 27, pp. 845-854, 1999.
7) England BS and Kammen MD: Energy resources and development in Vietnam. Annual Reviews Energy and Environment Vol. 18, pp. 137-67 , 1993.
8) Tran DM: Policy and strategy for biomass development and utilization in Vietnam. 2nd Biomass Asia Workshop. Thailand, 2005.
9) Nguyen DC: Biomass for electricity generation in Vietnam. The kick-off workshop: Information for the commercialization of Renewables in Asean (IRCA), 2004.
10) Nguyen MB: Biomass energy usage in Vietnam. Asian Regional Cook stove Program. Available at http://www.arecop.org/zip/ Biomass-vn-pres.pdf.
11) Nguyen TT: Biomass utilization development in Vietnam. 1st Biomass Asia Workshop. Tokyo, Jan 2005.
12) Truong NH: Current status of biomass utilization in Vietnam. 1st Biomass Asia Workshop. Tokyo, Jan 2005.
13) Nguyen DT: Biomass used as energy in Vietnam. Proceedings in International Workshops on Biomass Briquetting, New Dehli, Apr. 1995.
14) Kumar A, Bhattacharya SC, Pham HL: Greenhouse gas mitigation potential of biomass energy technologies in Vietnam using the long range energy alternative planning system model. Energy Vol. 28, pp. 627-654, 2003.
15) Nguyen LT and Tran QC: Potential of distributed power generation from biomass residues in Vietnam - Status and prospect. Workshop on Electricity Supply Industry in Transition: Issues and Prospect for Asia. Jan. 2004.
16) ESMAP: Vietnam renewable energy action plan - Technical Paper. The World Bank, Washington D.C. (USA). Mar 2002.
17) Nguyen HC: Geo-pedological study of the Mekong Delta. The Southeast Asian Studies, Vol. 31, No. 2, pp.158-186, 1993.
18) Vo HD: The Mekong Delta's Economy. MD Economic Forum 2007. Available at www.vccimekong.com.vn.
19) Vu VT: Vietnam's renewable energy and CDM policies. ICRA Kick-off workshop, Kuala Lumpur Aug., 2004.
20) MARD: Cultivation, husbandry and forestry database, available at http://www.mard.gov.vn/fsiu/data.
21) Bhattacharya SC, Arul Joe M, Kandhekar Z, Abdul Salam P,

Shrestha RM: Greenhouse gas emission mitigation from the use of agricultural residues: the case of rice husk. Energy Vol. 24, pp. 43-59, 1999.
22) Bhattacharya SC, Abdul Salam P, Runquing H, Somashekar HI, Racelis DA, Rathnasiri PG, Yingyuad R: An assessment of the potential for non-plantation biomass resources in selected Asian countries for 2010, Biomass and Bioenergy Vol.29, No.3, pp.153-166, 2005.
23) Koopmans A and Koppejan J: Agricultural and forest residues, Generation, utilization and availability. Paper presented at the Regional Consultation on Modern Applications of Biomass Energy, 1997, available at http://www.fao.org/DOCREP/006/AD576E/ad576e00.pdf.
24) FOA: Vietnam tropical forestry action plan programme: Fuelwood and Energy Sectoral Reviews, FOA 1992 (Vietnamese).
25) ENERTEAM: Identification of biomass energy projects in Southeast asia (Cambodia, Laos, and Vietnam) likely to be financed by Global Environmental programs, Vietnam Report. 2003.
26) Bhattacharya SC, Jossy M, Abdul Salam P: Greenhouse gas emissions and the mitigation potential of using animal waste in Asia. Energy Vol. 22, pp.1079-1085, 1997.
27) Coelho TS, Velazquez SMSG, Martins OS, Abreu FD: Biogas from sewage treatment used to electric energy generation, by a 30KW (ISO) micro-turbine. World Bioenergy Conference and Exhibition, Suecia Jun 2006.
28) Bioenergy Association of New Zealand: Biogas-Production of biogas, available at http://www.bioenergy.org.nz/biogas.asp.
29) Skrzypczak M: Biomass potential in Upper Silesia region in Poland. Example of utilization. Conference ENEF. Slovakia. 2006.
30) Harasimowicz M, Orluk P, Zakrzewska-Trznadela G, Chmielewski AG: Application of polyimide membranes for biogas purification and enrichment, Hazardous Materials Vol. 144, pp. 698 – 702, 2007.
31) Overend PR and Craig CK: Biomass energy Resource Enhancement: The move to modern secondary energy forms, Paper for UNIDO Symposium on Development and Utilization of Biomass Energy resources in developing countries.
32) Nguyen TL: Urbanization and Sustainability in Asia: Case studies of good practice, Chapter 14: Vietnam report. Asian development Bank (ADB), 2006.
33) UNs Economic and Social Affairs: World urbanization prospects, The 2007 revision. New York (USA) 2008.
34) Sajjakulnukit B, Yingyuad R, Maneekhao V, Pongnarintasut V, Bhattacharya SC, Abdul Salam P: Assessment of sustainable energy potential of non-plantation biomass resources in Thailand. Biomass and Bioenergy Vol. 29, pp. 214-224, 2005.
35) PREGA: Bagasse and other biomass-fired power plant and Suoi Chum Small hydropower plant: An Assessment report. Jan. 2006.
36) MARD: Fruit Development in the Mekong Delta South Vietnam – Newsletter Dec. 2003.
37) Nguyen TK: Marketing Systems of Melaleuca Forest Products. Proceedings of National Seminar on Forest-Based Development in the Long Xuyen Quadrangle, Mekong Delta, Vietnam. 1995.
38) Sugiyama M, Iddamalgoda A, Oguri K, Kamiya N: Development of livestock sector in Asia: An analysis of present situation of livestock sector and its importance for future development, Gifu City Women's College Vol. 52, pp. 1-9, 2003.
39) FAO: Livestock sector brief – Vietnam, Report of Livestock Information. Sector analysis and Policy branch. FAO, 2005.
40) USDA Foreign Agriculture Service-Global Agriculture information network: Vietnam livestock and products Annual 2006. available at http://www.fas.usda.gov/gainfiles/200609/ 146228906.pdf.
41) WHO: Diet, Nutrition and the Prevention of Chronic Diseases. WHO Technical report series 916, Geneva 2003.
42) Dang TT, Saito O, Morioka T: Toward sustainable biomass use in rural provinces of Vietnam's Mekong Delta. Proceedings of 35th Annual meeting of Environmental System Research. Tokyo Oct. 2007, pp 167-172.
43) Jennings V, Lloyd-Smith B, Ironmonger D. (1999) HH size and the poison distribution, Journal of the Australian Population Association, Vol. 16, pp 65-83.
44) ENERTEAM: Potential for energy generation from wood and selected agro-industrial residue in Vietnam. Vietnam, 1997.
45) Bhattacharya SC and Dang NQT: The cogeneration potential of sugar industry in Vietnam, OPEC material, 2004.
46) Bhattacharya SC and Dang NQT: Economic buy-back rates for electricity from cogeneration: Case of sugar industry in Vietnam. Energy Vol. 29, pp. 1039-1051, 2004.
47) Tran MT: Biomass utilization in Vietnam. The 2nd Biomass Asia workshop, Thailand Dec. 2005.
48) Le VB, Hoang BQ, Pham VN, Kanetena Y, Kobayashi K, Hiraoka H: Development of simple small dryer suitable for small farms in remote areas. Omorice Vol. 9; pp. 140-143, 2001.
49) ENERTEAM: Improvement of rice husk-fired brick kilns in the Mekong Delta. Project document 2007. available at: http://www.enerteam.org/enerteam/?module=3&do=1&id=5.
50) MARD: Agriculture and Rural development, 5-year plan (2006 – 2010). MARD, Hanoi 2005.
51) Rosillo-Calle F, Groot P, Hemsteok FL, Woods J: The Biomass assessment handbook: Bioenergy for Sustainable Environment. Published by Earth scan, UK and USA 2007.
52) Le QD: Participatory Rural Environmental Management: Synthesized report. Hanoi 2004. available at: ftp://ftp.fao.org/docrep/fao/008/af329e/af329e00.pdf.
53) GSO and United Nations Population Funds: The 2004 Vietnam migration survey: Internal migration and related life course events, General Statistic Office of Vietnam, Hanoi 2006.
54) MARD: National food security to 2020, the vision to 2030, Hanoi 2008.
55) Garivait S, Bonnet S, Kamnoed O: Air pollutant emissions from paddy residues open burning and their potential for bioenergy in the Mekong River Basin Sub-region, GMSARN International Conference on Sustainable Development: Challenges and Opportunities for GMS, 2007.
56) Meinrat OA: Biomass burning: its history, use, and distribution and its impact on environmental quality and global climate. In: Global biomass burning: Atmospheric, climatic, and biospheric implications, MIT Press, Cambridge, M.A, 1991.
57) Crutzen PJ and Meinrat OA: Biomass burning in the tropics: Impacts on atmospheric chemistry and biogeochemical cycles, Science Vol. 250, pp.1669-1678, 1990.
58) Massaquoi JGM: Phase II Economic value and supply potential of rice residues in Sierra Leone. Commonwealth Science Council, Technical Publication Series No. 220. London, UK, 1986.
59) Summers MD: Using rice straw for energy production: economics, energetic and emissions, available at http://faculty.engineering.ucdavis.edu/jenkins/projects/RiceStraw/RiceStrawDocs/SummersEBS216FinalReport.pdf.
60) GAMBAS: Environmental Sustainability of Brackish Water Aquaculture in the Mekong Delta - Vietnam, 2000. available at: http://www.com.univ-rs.fr/IRD/gambas/summary.htm.
61) Nguyen AT and Lefevre T: Analysis of household energy demand in Vietnam. Energy Policy Vol.24, No.12, pp.1089-099, 1996.
62) ESMAP: Rural and household energy issues and options. Report No. 161/94, ESMAP, 1994.
63) Institute of Energy: A case study on wood energy data collection and assessment and decentralized wood energy planning in Vietnam- Final report, Hanoi 2001.
64) Institute of Energy: Cooking devices in Vietnam, cost and efficiency, Hanoi 2002.
65) Bersqvist M, Wardh S, Das A, Ahlgren E: A techno-economic assessment of rice husk-based power generation in the Mekong River Delta of Vietnam. Energy research Vol. 32, pp. 1136-1150, 2008.