CHAPTER IV
BIOMASS ENERGY ACQUISITION OF HOUSEHOLDS IN COMMUNITIES AT DIFFERENT LEVELS OF URBANIZATION IN NORTHEAST THAILAND AND POSSIBLE STRATEGIES FOR SUSTAINABLE MANAGEMENT OF HOUSEHOLD SOURCES OF FUELWOOD [1]

1. Introduction

Promotion of production and use of renewable energy has received high priority in many countries in the face of the diminishing supply and increasing price of fossil fuel (REN21, 2008). It is widely anticipated that renewable energy sources which exist naturally will play more important role in the future (BP p.l.c., 2008). Biomass is viewed as an especially promising type of renewable energy because it is widely available, can be derived from a variety of sources (e.g., forest products, wood products, energy crops and agricultural residues), can be locally produced in most rural communities, and is considered to be a type of "green" energy (Bartuska, 2006). Although currently biomass energy accounts for only about 2.2% of the total world energy consumption (REN21, 2006), it is quite important in developing countries in which 70 % of it is used by the residential sector, especially in rural areas where 2.4 billion people live (RWEDP, 2002). There are 80 countries around the world that traditionally use biomass as an important energy source, of which Asian countries consume more than 80 % of the total biomass energy. There is evidence that biomass energy consumption has been increasing lately in several countries, particularly in India and China (IEA, 2007; REWDP, 1999, 2002). In Thailand, biomass energy accounted for 15.8 % of the total energy consumption in the country in 2004 (DEDE, 2006). It is, thus, a potential source of alternative energy that is worth exploring. It

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has been shown that an increase of biomass energy use is possible in many countries (Parikka, 2004) but whether or not this is the case in Thailand is still questionable.

In the course of development, people generally choose to switch from biomass fuels to more convenient energy sources such as LPG, electricity, and petroleum products. Several factors have been found to influence these shifts in household energy consumption, both the amount consumed and the types of energy sources used. The main factors are level of urbanization, economic development, and living standards. Of these factors, the level of urbanization has been found to have the greatest influence on the pattern of household energy consumption (Pohekar et al., 2005; Cai and Jiang, 2008; Dhingra et al., 2008) but changes in types of energy used by households and a relative decline in the share of biomass energy have been observed even in rural areas, (Mahapatra and Mitchell, 1999; Senelwa and Sims, 1999; Dube, 2003; Xiaohua and Zhenmin, 2005; Ouedraogo, 2006). These studies all appear to support the conventional assumption that the role of biomass energy will diminish, and even completely disappear, as rural communities become more urbanized. However, there is considerable evidence that biomass energy still plays an important role as a household energy source, particularly in countries in Africa (Madubansi and Shackelton, 2006) and the Asia-Pacific region (Gumartini, 2009). Even in the developed country like Australia, 23% of households still used fuelwood for domestic purposes with an average of 4.5-5.0 million tons per year (Paul et al., 2006). In Thailand, a study of energy consumption by urban households carried-out in 1989-90 found that in Bangkok 23.3 % of households used charcoal and 1.2 % used fuelwood while in Chiang Mai 63 % used charcoal and 16 % used charcoal (Pongsapich et al. 1994). A recent study on charcoal utilization in Khon Kaen province of Northeast Thailand (Nansaior et al., 2006) revealed that a substantial amount of charcoal is still consumed in the highly urbanized parts of the Khon Kaen municipality. Moreover, stacks of firewood under the houses are still commonly observed in suburban villages in Northeast Thailand, and biomass energy seems to still be relied on by many households in these semi-urbanized villages. Such evidence should call into question the conventional assumption that biomass energy use has no continuing importance for the national energy budget of Thailand and other developing countries.

To examine the extent to which biomass energy still plays an important role as a source of energy for household consumption across the urbanization spectrum of the communities, we have conducted a study on energy utilization of households in three villages in Khon Kaen province in Northeast that represented the rural, suburban and urban communities. Data were collected on energy uses at household level using a formal survey with questionnaire, field observation and field measurement. The results showed that total household energy consumption was not much different among the three study communities, but, as expected, the share of biomass energy declined with urbanization. However, the decline in the share of biomass was rather small when moving from rural to suburban, but was more substantial when moving from suburban to urban, with the shares being 47.1, 34.5 and 9.9 % of total household energy consumption for the rural, suburban and urban communities, respectively. Both firewood and charcoal were used primarily for cooking and a small amount for home industry, while LPG and electricity were used entirely for living, and gasoline was mostly used for transportation with a small amount used for agriculture. It was concluded that the relative importance of biomass energy has decreased in the urban community (although the absolute quantity used remains quite large) but it still has an extremely important role as a source of household energy in the rural and suburban communities in which most of the country's population live (Nansaior et al., n.d.).

The considerable quantities of biomass used by households in the rural and suburban communities has raised a major question of whether the local supply of biomass would be sufficient to meet the demand, particularly in the long run, without resorting to further destruction of natural forests. This paper presents the results of another part of our study mentioned above which attempted to address the above question by analyzing the data collected in the three communities in Khon Kaen province. Specifically, this part of the study examined the patterns of biomass acquisition among households in different groupings (communities with different levels of urbanization, different levels of biomass utilization and different occupations), and explored whether the supply of biomass for household consumption could be managed in such a way that they can be energy self-sufficient while producing biomass in a sustainable manner.

2. Materials and Methods

The study was conducted in three villages in Khon Kaen province of Northeast Thailand that represent different points along the rural-urban continuum of communities, i.e., rural, suburban and urban. The details of procedures for data collection have been described in a separate paper (Nansaior et al., n.d.) and are only briefly presented here.

Khon Kaen province was selected for this research because it includes communities ranging from quite rural to highly urban. The provincial capital, Khon Kaen city, is the sixth most populous city in Thailand (DPA, 2008) and displays a high level of urbanization. Khon Kaen city is large enough that its impact is strongly felt in surrounding villages, with many having developed a strongly suburban character in recent years. However, some villages, which are located in more remote districts, and enjoy less easy access to the city, still retain a rural character.

Based on their distance from Khon Kaen city and the proportion of agricultural land to the total area of the community, Ladna Piang, Nongbua Deemee and Srijan villages were selected to represent the rural, suburban and urban communities, respectively. Additional criteria used in selecting these villages were the number of households (100-400), population density, total community area, level of infrastructure and diversity of occupation of households within the community.

Data were collected on energy uses at the household level using a formal questionnaire survey, field observation and field measurements. For Ladna Piang and Nongbua Deemee, the rural and suburban communities, 50 % of the households, randomly selected, were interviewed and observed for household uses of different energy sources. The 50 % figure was employed to make sure that the sampled households covered all the household types classified by different factors. For the urban community Srijan, which is a small community, data were collected for all the households. A total of 288 households were interviewed in the three communities but 16 of these were households that used very high quantities of energy (>100,000 MJ/hh/yr) in production activities so they were excluded from this analysis. The questionnaire was pretested before conducting the actual survey.

The questionnaire included question about the characteristics of household, question about the amount of energy used from each source, the activities for which that energy source was used and the way biomass was acquired that provided to data used in this amount. The sources of energy are divided into biomass (firewood, charcoal) and non-biomass, which includes electricity, LPG and gasoline. The uses of energy are divided into cooking, living, transportation, agriculture and other income generation activities.

The amounts of firewood and charcoal consumed by each household were measured by asking the appropriate member of the household to make a separate pile of the amount of wood or charcoal that he or she anticipated that they would use in the following seven days. That amount was weighed and kept separately from the main supply. After five days, the household was re-visited and any unused wood or charcoal was weighed and recorded.

All the data obtained were converted into a standard energy unit energy unit (Mega Joules, MJ) to allow ready comparisons.

The absolute quantities of the different sources of energy and their relative shares for each household were computed. In this study, variations in the relative shares of biomass energy for the individual households were examined. Households were divided into groups defined according to the different levels of the share of biomass energy to total energy consumption by the household. They were also divided by occupations which included employees of a government office or private enterprise with regular income, business owners, daily wage workers with irregular income and those earning their living from agriculture. These household groups and occupations were analyzed for their patterns of biomass acquisition which included (1) obtained from collecting their own land (paddy fields, uplands, house plot), land belonging to neighbors, and public land (community forest, river forest, and roadside), (2) purchased and (3) both collected and purchased. The extent of household self-sufficiency in producing biomass was determined. Selected households that were self-sufficient in terms of producing all of their own biomass energy were interviewed to obtain information on the ways in which they acquired biomass for household use and the ways in which they managed production of fuelwood for household uses. Assessment was then made of the long term prospects of biomass as a source of energy for household consumption. Figure 1 illustrates the conceptual framework for biomass energy acquisition used in the present study.

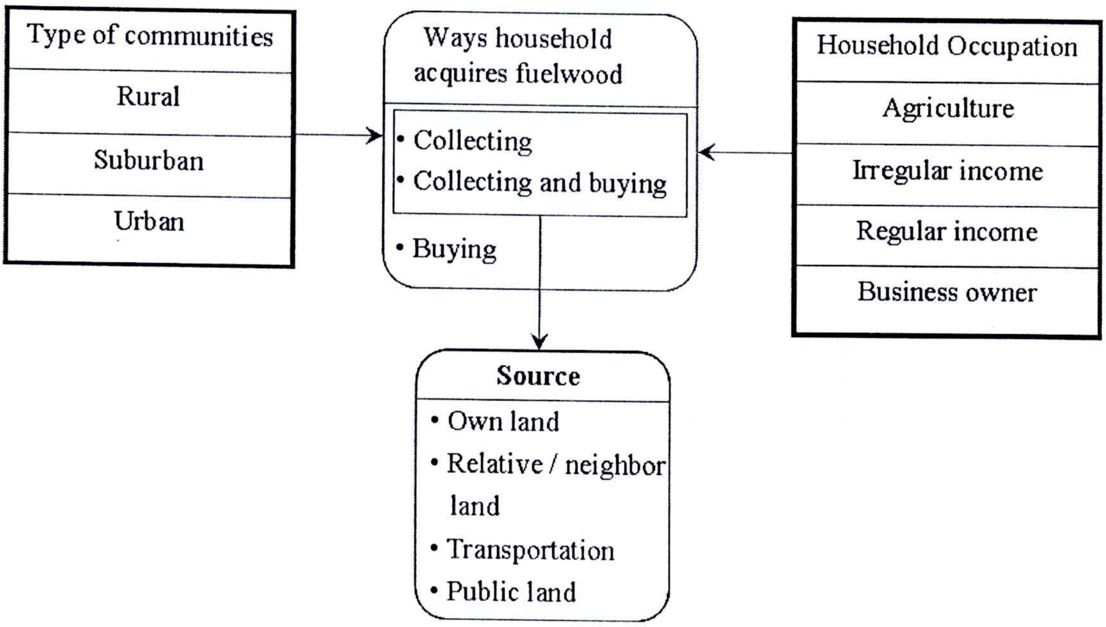

Figure 1 Conceptual framework for biomass energy acquisition of households in communities with different levels of urbanization.

3. Results

3.1 The studies sites

The villages of Ladna Piang, Nongbua Deemee, and Srijan, all located in the Muang district of Northeast Thailand's Khon Kaen province, were selected for this study. Ladna Piang represent a typical rural community, Nongbua Deemee represents a suburban community and Srijan represents an urban community.

The rural village of Ladna Piang, is situated 32 km from Khon Kaen city, and is located 15 km from the main highway, but connected to it by a paved road. With a land area of 832.5 ha, and population density of 2 persons/ha, it has the largest land area and lowest population density of the three villages. Most of the area (97 %) is agricultural land in which rice, cassava, sugarcane and vegetables are grown. The community has a low occupational diversity, with a large majority (93.8 %) of the household heads working as farmers; the remainders are wage laborers (4.6 %) and employees of government offices or private enterprises (1.5 %). The village has a day-care facility for pre-school children, primary and secondary schools, but has no health service center. All households have access to electricity and mobile phone systems, and tap water is available through the municipal system. Most of the houses are typical rural Thai houses, constructed from wood with a raised floor and an empty space underneath; there are also a few modern style houses in the village. Rice barns are generally found in the residential areas, around which firewood is stored. The lifestyle in this community is typically rural; women still do handicrafts such as silk weaving when they are free from farming responsibilities.

By contrast, the urban village of Srijan is located in Khon Kaen city and has the smallest land area (6.8 ha) and the highest population density (132 persons/ha) of the three (Table 1). There is no agricultural land in this village, but there are a few uninhabited plots, owned by some affluent families, that are used by some villagers to raise cattle and collect firewood. With its urban location and proximity to Khon Kaen city, Srijan has easy access to all the usual urban facilities and infrastructures, e.g., electricity, telephone, tap water, education services from primary school to university levels, public and private hospitals, transportation, supermarkets, shopping centers, government and municipality services, etc. Housing is built in modern styles, in the form of individual houses, townhouses and apartments made from concrete. Almost half of the households (49.2 %) have regular income from members who are employees of public organizations or private enterprises. The remaining households are those with business owners (26.2 %) and daily wage workers (24.6 %). None of these urban households have agriculture as their main occupation (Table 2). Their life style is typical of those who live in the provincial cities of Thailand.

Table 1 Characteristics of the three study communities.

Characteristics	Rural: Ladna Piang	Suburban: Nongbua Deemee	Urban: Srijan
Distance from Khon Kean city (km.)	32	12.5	0
Total households (no.)	343	240	118
Total population (person)	1620	1624	895
Total community area (ha)	832.5	75.2	6.8
Population density (persons/ha)	2	22	132
Proportion of agriculture land	high = 0.97	medium = 0.72	very low
Occupation diversity	low	medium	high
Infra-structure	low	medium	high

Sources: Anonymous, 2006; RDIC, 2008.

The suburban village of Nongbua Deemee, shares some characteristics of both Ladna Piang and Srijan, being more rural in some ways and more urban in others. It is located12.5 km from Khon Kaen city, to which it is connected by a good-quality road, giving residents access to all the facilities and infrastructures available in Khon Kaen city, albeit with less convenience than the households in Srijan village. Total land area is intermediate among the three communities (75.2 ha), as is the population density (22 persons/ha) (Table 1). Agricultural land accounts for 72% of the total community area, but many plots lay fallow because the owners either have other occupations or are rich people outside the community. There are fewer farmers (48.4 %) but more daily-paid workers (36.6 %), government and private employees (10.8 %) and business owners (4.3 %) in this village than in Ladna Piang (Table 2).Occupational diversity is medium. Nongbua Deemee also has more modern-style houses than its rural counterpart, as well as more people with an urban life style.

Distribution of households of different sizes in the three communities varied to some extent. While the majority of households in the rural and suburban communities (63.8 % for the rural and 68.8 % for the sub-urban community) were of medium size (3-5 persons), the rural community had more large size (>5 persons) households (22.3 %) than small size (<3 persons) households (13.8 %). The suburban community had fewer small size households (12.9 %) than large size households (18.3 %) (Table 2). The size distribution of households in the urban community also differed from those of the rural and suburban communities, with almost half (49.2 %) of the households being medium size, 33.8 % being small size and only 16.9 % being large size. Overall, the size of households tended to decrease with urbanization. Means for household size of the rural, sub-urban and urban communities were 4.2, 3.9 and 3.3 persons/hh, respectively.

The distribution of households of different income levels were also similar for the rural and suburban communities, with the majority (> 60 %) being in the medium income class, affluent households accounting for some 20 % and the remainder representing poor households. By contrast, in the urban community, more than half (56.9 %) of the households were affluent, while 40 % had medium income, and only 3.1 % could be considered poor (Table 2). Average household incomes for the rural, suburban and urban communities were 3,611, 3,384 and 6,279 US$/year, respectively.

Differences in the area of land cultivated per household among the three communities were quite clear, with the area decreasing with urbanization. In the rural village, the majority of the households cultivated large and medium sized areas of land (31.5 and 36.2 %, respectively), but most of the households in the suburban community cultivated small (15.1 %) or very small (75.3 %) areas of land. Not surprisingly, over 90 % of the households in the urban community had only small or very small plots of land (Table 2). The average land areas were 3.62, 0.63 and 0.02 ha per household for the rural, suburban and urban communities, respectively.

Percentages of households that used firewood were quite high for the rural (94 %) and suburban (80 %) communities, but much lower (46 %) for the urban community (Table 3). The same trend was also observed for the percentages of households that used charcoal, but the decrease was not pronounced as for firewood, being 88, 83 and 74 % of households in the rural, suburban and urban communities, respectively. Use of LPG increased with urbanization, with the percentages of households that used LPG being 48, 69 and 71 %, for the rural, suburban and urban communities, respectively. All households in all of the communities used electricity for their living. Most of the households had motorcycles, but the percentage declined with urbanization, being 91, 88 and 71 % for the rural, suburban and urban communities, respectively, whereas ownership of cars or trucks increased with urbanization, being 22, 25, and 42 % of households for the rural suburban and urban communities, respectively.

3.2 Shares of biomass energy for the individual households in the three communities

In all the three study communities, total energy consumption varied greatly among households, ranging from 10,602 to 167,278 MJ/hh/yr with an average of 158,018 MJ/hh/yr for the rural community, from 11,289 to 217,354 MJ/hh/yr with an average of 107,891MJ/hh/yr for the suburban community, and from 19,339 to 191,942 MJ/hh/yr with an average of 38,814 MJ/hh/yr for the urban community. The share of biomass energy in the total household energy mix also differed greatly, ranging from 6% to 90 %, with an average of 47 % for the rural community, from 1% to 88 %, with an average of 37 %, for the suburban community, and from 0.2% to 66 %, with an average of 13 %, for the urban community (Figure 2). Clearly, the share represented by biomass energy out of the total amount of energy consumed by households declined as the communities become more urbanized. However, the share of biomass declined only slightly when going from the rural to suburban community but the decline was much more substantial when going from the suburban to the urban community. It was also found that biomass energy was highly correlated with total energy consumption for households in the rural and suburban communities but not for the urban community, with the correlation coefficients being 0.65**, 0.57** and 0.29 for the rural, suburban and urban communities, respectively.

Table 2 Percentages of households types for the individual classifications in the three study communities.

Household type	Rural: Ladna Piang (130 hh)	Suburban: Nongbua Deemee (93 hh)	Urban: Srijan (65 hh)
Occupation*			
Regular income	1.5	10.8	49.2
Having own business	0.0	4.3	26.2
Irregular income	4.6	36.6	24.6
Agriculture	93.8	48.4	0.0
Household size			
Small (< 3 persons)	13.8	18.3	33.8
Medium (3-5 persons)	63.8	68.8	49.2
Large (> 5 persons)	22.3	12.9	16.9
Average household size (person)	4.2	3.8	3.5
Household income**			
Below poverty line (< 439 US$/yr)	7.7	16.1	3.1
Medium (439-3,864 US$/yr)	65.4	60.2	40.0
Well being (> 3,864 US$/yr)	26.9	23.7	56.9
Average household income (US$/yr)	3,584.4	3,821.5	7,265.3
Cultivated area			
Very small (0-1 ha.)	16.9	75.3	100.0
Small (1-2 ha.)	15.4	15.1	0.0
Medium (2-4 ha.)	36.2	8.6	0.0
Large (>4 ha.)	31.5	1.1	0.0
Average area (ha.)	3.6	0.7	0.02

*Regular income = household with monthly income from public or private organization; Irregular income = daily-paid worker.

**1 US$ =33.64 Thai Baht.

Table 3 Percentages of sampled households that used different sources of energy in the three study communities.

Type of energy used	Rural: Ladna Piang (130 hh)	Suburban: Nongbua Deemee (93 hh)	Urban: Srijan (65 hh)
firewood	94	80	46
charcoal	88	83	74
LPG	48	69	71
electricity	100	100	100
gasoline for agriculture	88	43	0
gasoline for motorcycle	91	88	71
gasoline for car	22	24	42

The shares of biomass energy in household energy consumption of all the sampled households showed a more or less normal distribution, with the highest percentage (36 %) being in the class of households getting 26-50% of their total energy from biomass and declining towards both the higher and lower share levels. Of the 272 households in the whole sample, more than 90 % used biomass as a source of household energy, while only 9.2 % did not use biomass at all for their household energy (Table 4).

Households with different occupations show considerable differences in the extent of their reliance on biomass energy. The majority of the agricultural households were concentrated in the 26-50 % and 51-75 % biomass share classes, with the frequencies being 42.9 % and 36 %, respectively. The majority of the irregular income households were concentrated in three biomass share classes; the highest percentage (30.9 %) was in the 26-50 % share class, followed by 23.6 % in the 51-75 % share class and 21.8 % in the 1-25 % share class. On the contrary, most households of business owners (61.1 %) were in the low share class of biomass (1-25 %), and a considerable proportion (33.3 %) did not use biomass at all. Similarly, for all households with regular income the share of biomass energy was less than 50%

of their total household energy consumption, with 26.3 % being in the 26-50% biomass share class, 47.4 % in the 1-25 % share class, while 26.3 % did not use biomass at all (Table 4). Apparently, agricultural households and irregular income households used more biomass energy than households with business owners and employees of government offices and private enterprises with regular incomes.

These patterns of frequency distribution of biomass shares for households with different occupations were reflected in the each of the individual communities (Table 4). For each community, the frequency distribution of households in different levels of biomass share of total energy use closely reflected the relative proportions of the occupations of households in the respective community. Thus, the rural and suburban communities had high percentages of households with high shares of biomass in total household energy use because these two communities had high proportions of agricultural and irregular income households, while the urban community had low share of biomass energy because most of the households were business owners and regular income households.

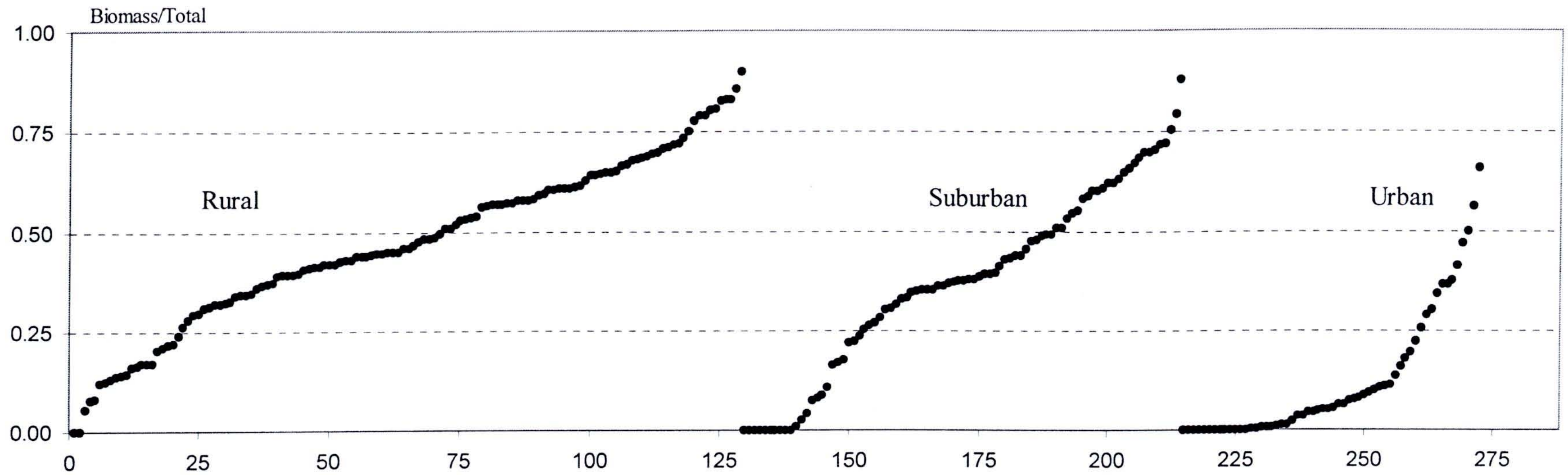

Figure 2 The share of biomass energy in the total household energy of households in the rural, suburban and urban communities.

Table 4 Numbers and percentages of households at different levels of biomass energy share (% of total household energy consumption) for different occupations in the rural, suburban and urban communities.

Community/Occupation	Not use (0 %)		1- 25 %		26 – 50 %		51 – 75 %		>75 %		Total	
	No.	%	No.	%	No.	%	No.	%	No.	%	No.	%
Rural	**2**	**1.6**	**19**	**14.7**	**50**	**38.8**	**48**	**37.2**	**10**	**7.8**	**129**	**100**
Regular income	*0*	*0.0*	*1*	*50.0*	*1*	*50.0*	*0*	*0.0*	*0*	*0.0*	*2*	*100*
Business owner	*0*	*0.0*	*0*	*0.0*	*0*	*0.0*	*0*	*0.0*	*0*	*0.0*	*0*	*0.0*
Irregular income	*0*	*0.0*	*1*	*16.7*	*1*	*16.7*	*0*	*0.0*	*4*	*66.7*	*6*	*100*
Agriculture	*2*	*1.7*	*17*	*14.0*	*48*	*39.7*	*48*	*39.7*	*6*	*5.0*	*121*	*100*
Suburban	**10**	**11.8**	**13**	**15.3**	**37**	**43.5**	**22**	**25.9**	**3**	**3.5**	**85**	**100**
Regular income	*3*	*37.5*	*1*	*12.5*	*4*	*50.0*	*0*	*0.0*	*0*	*0.0*	*8*	*100*
Business owner	*2*	*50.0*	*2*	*50.0*	*0*	*0.0*	*0*	*0.0*	*0*	*0.0*	*4*	*100*
Irregular income	*4*	*12.1*	*3*	*9.1*	*12*	*36.4*	*12*	*36.4*	*2*	*6.1*	*33*	*100*
Agriculture	*1*	*2.5*	*7*	*17.5*	*21*	*52.5*	*10*	*25.0*	*1*	*2.5*	*40*	*100*
Urban	**13**	**22.4**	**33**	**56.9**	**10**	**17.2**	**2**	**3.4**	**0**	**0.0**	**58**	**100**
Regular income	*6*	*21.4*	*16*	*57.1*	*5*	*17.9*	*1*	*3.6*	*0*	*0.0*	*28*	*100*
Business owner	*4*	*28.6*	*9*	*64.3*	*1*	*7.1*	*0*	*0.0*	*0*	*0.0*	*14*	*100*
Irregular income	*3*	*18.8*	*8*	*50.0*	*4*	*25.0*	*1*	*6.3*	*0*	*0.0*	*16*	*100*
Agriculture	*0*	*0.0*	*0*	*0.0*	*0*	*0.0*	*0*	*0.0*	*0*	*0.0*	*0*	*0.0*
Total-regular income	***9***	***23.7***	***18***	***47.4***	***10***	***26.3***	***1***	***2.6***	***0***	***0.0***	***38***	***100***
Total-business owner	***6***	***33.3***	***11***	***61.1***	***1***	***5.6***	***0***	***0.0***	***0***	***0.0***	***18***	***100***
Total-irregular income	***7***	***12.7***	***12***	***21.8***	***17***	***30.9***	***13***	***23.6***	***6***	***10.9***	***55***	***100***
Total-agriculture	***3***	***1.9***	***24***	***14.9***	***69***	***42.9***	***58***	***36.0***	***7***	***4.3***	***161***	***100***
Total-all households	**25**	**9.2**	**65**	**23.9**	**97**	**35.7**	**72**	**26.5**	**13**	**4.8**	**272**	**100**

3.3 Acquisition of biomass by the individual households

In this section, the various ways in which households acquired biomass fuel are examined and factors influencing their choice of sources are analyzed. There are three ways by which households obtained biomass fuel: 1) by collecting it, either from their own land, neighbors' land or public land, 2) by purchasing it, and 3) by both collecting and purchasing it. The percentage of households relying on collecting tends to decrease as communities became more urbanized whereas the percentage of households relying on purchasing increases. In the rural and suburban communities, the vast majority of households (89.0 % and 81.3 % respectively) obtained all their biomass fuel by collecting it, where as in the urban community only about half (53.3 %) of households collected some or all of their fuel whereas 42.0 % purchased all that they use (Table 5).

The share of biomass energy in the total amount of energy used by households did not show any clear relationship to ways in which it was obtained (Table 5). However, occupation appeared to strongly influence the choice of ways to obtain biomass fuel. Table 6 shows that, in all communities, the majority (58.3 %) of households that own businesses purchased all of their biomass energy and more than one-third (37.9 %) of households with regular income also purchased all of their supply, whereas most agricultural households (89.9 %) and those with irregular income (70.8 %) relied on collecting to obtain their biomass energy supplies. This suggests that these latter two groups should be the focus of future efforts to promote additional biomass energy use.

Most (62.7 %) of the agricultural households collected biomass fuel only from their own land whereas households with irregular incomes obtained firewood from several different sources, including public land (27.1 %), their own land (16.7 %) or both public land and their own land (16.7 %). A much smaller number of households of both types also got fuel from land belonging to neighbors (Table 7). Table 8 shows the specific sources from which households in the different communities obtained biomass fuel. Rural households who collected their own biomass energy mostly obtained fuel from trees in their paddy fields (85.0 %) and from public forest land (22.0 %), most suburban households got biomass fuel either from public forest land

(44.0 %) or their own paddy fields (40.0 %) and only 9.3 % got it from neighbors' land, while urban households collected fuel from public forest land (20.0 %), their own house plots (8.6 %), and land of their neighbors (6.7 %).

On average, rural households consumed 20,434 MJ/yr of biomass energy (11,243 MJ from 703 kg of wood, 9,191 MJ from 318 kg of charcoal) while suburban ones used 18,454 MJ/yr (10,760 MJ from 673 kg of wood, 7,695 MJ from 266 kg of charcoal). Using a wood to charcoal conversion rate of 19.2% for Eucalyptus, which is typical of the crude kilns most commonly employed in Northeastern Thailand, this represents the energy value of 2,362 kg of wood for rural households and 2,062 kg of wood for suburban households. Since mature Eucalyptus trees have an average annual growth increment of 35 kg, the annual fuelwood consumption of a rural household could be sustainably met by 68 trees while a suburban household would need only 59 trees At the typical planting density for Eucalyptus in Northeast Thailand of 3,750 trees/ha, the area required to meet a typical household's current annual fuelwood requirement would be only 180 m^2 per rural household and 160 m^2 per suburban household. As is shown by Figure 3, the majority of households in the rural village own much more land than this and should have no difficulty in reserving this small area for biomass fuel production. Moreover, if, as is already common local practice, the trees were planted in a line on the paddy bunds or property boundary lines with a spacing of 1.5 m between trees, instead of in a single block, only 102 m of bund or boundary line would need to be planted with eucalyptus trees to meet the needs of a rural household and 89 m of bund or boundary line would supply a suburban household for a year. Planting trees in this fashion does not take much land away from cultivation of food and cash crops. Therefore, it does not appear that availability of land to grow fuelwood is likely to be an important limiting factor on the ability of most rural and suburban villagers to sustainably meet their biomass energy needs in the long-term.

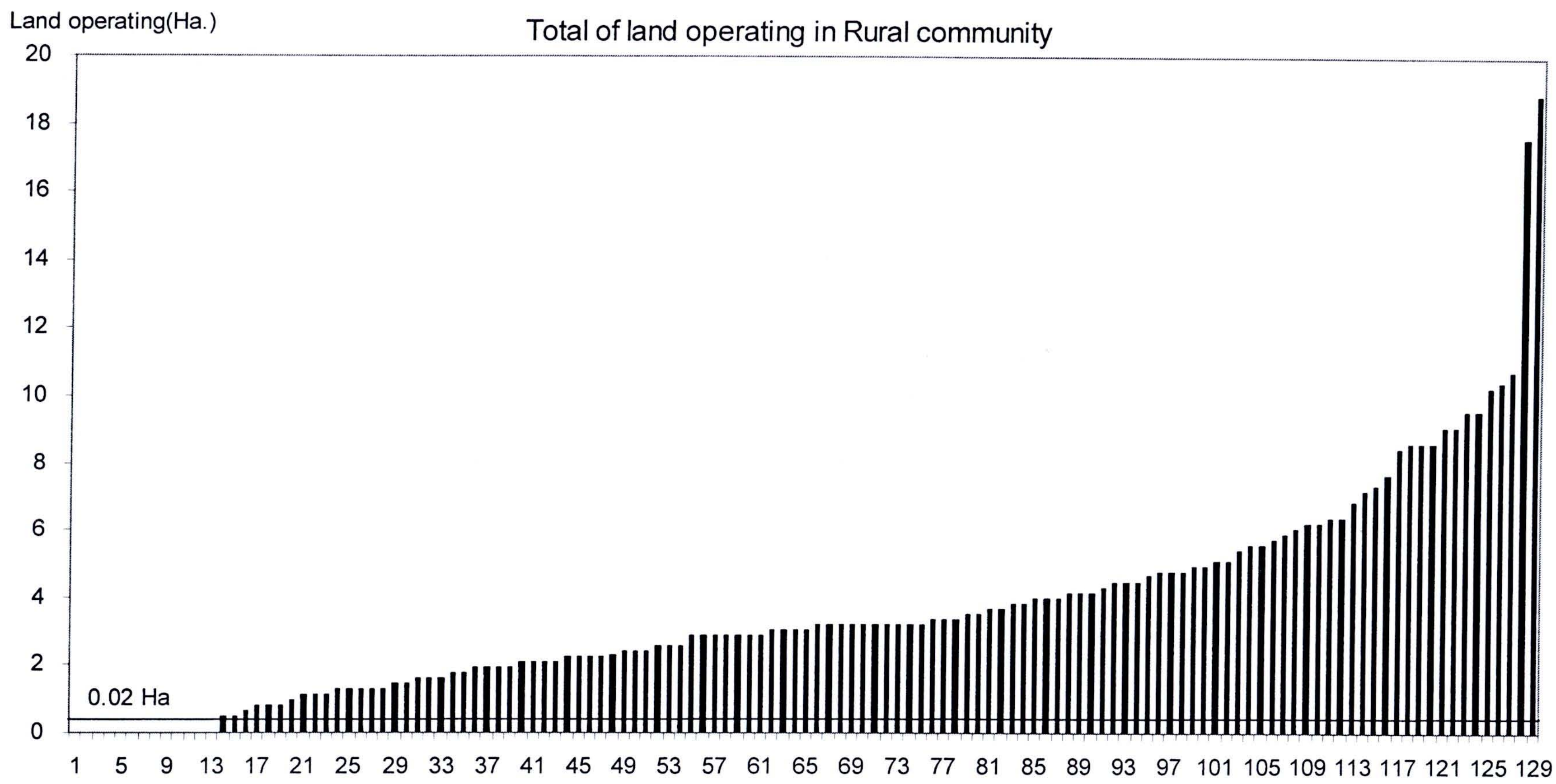

Figure 3 Potential of households in the rural village that own much more land than the needs

Table 5 Numbers and percentages of households that acquired biomass in different ways for the individual levels of the share of biomass energy (% of total household energy consumption) in the rural, suburban and urban communities.

Community/Share of	Collecting		Purchased		Collecting + Purchased		Total	
biomass energy (%)	No.	%	No.	%	No.	%	No.	%
Rural	**113**	**89.0**	**10**	**7.9**	**4**	**3.1**	**127**	**100**
1-25 %	*15*	*78.9*	*4*	*21.1*		*0.0*	*19*	*100*
26-50 %	*45*	*90.0*	*3*	*6.0*	*2*	*4.0*	*50*	*100*
51-75 %	*44*	*91.7*	*2*	*4.2*	*2*	*4.2*	*48*	*100*
>75 %	*9*	*90.0*	*1*	*10.0*		*0.0*	*10*	*100*
Suburban	**61**	**81.3**	**11**	**14.7**	**3**	**4.0**	**75**	**100**
1-25 %	*9*	*69.2*	*4*	*30.8*		*0.0*	*13*	*100*
26-50 %	*32*	*86.5*	*3*	*8.1*	*2*	*5.4*	*37*	*100*
51-75 %	*17*	*77.3*	*4*	*18.2*	*1*	*4.5*	*22*	*100*
>75 %	*3*	*100.0*		*0.0*		*0.0*	*3*	*100*
Urban	**24**	**53.3**	**19**	**42.2**	**2**	**4.4**	**45**	**100**
1-25 %	*14*	*42.4*	*18*	*54.5*	*1*	*3.0*	*33*	*100*
26-50 %	*8*	*80.0*	*1*	*10.0*	*1*	*10.0*	*10*	*100*
51-75 %	*2*	*100.0*		*0.0*		*0.0*	*2*	*100*
>75 %	*0*	*0.0*		*0.0*		*0.0*	*0*	*100*
Total: 1-25 %	***38***	***58.5***	***26***	***40.0***	***1***	***1.5***	***65***	***100***
Total: 26-50 %	***85***	***87.6***	***7***	***7.2***	***5***	***5.2***	***97***	***100***
Total: 51-75 %	***63***	***87.5***	***6***	***8.3***	***3***	***4.2***	***72***	***100***
Total: >75 %	***12***	***92.3***	***1***	***7.7***	***0***	***0.0***	***13***	***100***
Total-all households	**198**	**80.2**	**40**	**16.2**	**9**	**3.6**	**247**	**100**

Table 6 Numbers and percentages of households that acquired biomass in different ways for the individual occupations in the rural, suburban and urban communities.

Community/Share of biomass energy (%)	Collecting		Purchased		Collecting + Purchased		Total	
	No.	%	No.	%	No.	%	No.	%
Rural	**113**	**89.0**	**10**	**7.9**	**4**	**3.1**	**127**	**100**
Regular income	*1*	*50.0*	*1*	*50.0*		*0.0*	*2*	*100*
Business owner		*0.0*		*0.0*		*0.0*	*0*	
Irregular income	*4*	*66.7*	*2*	*33.3*		*0.0*	*6*	*100*
Agriculture	*108*	*90.8*	*7*	*5.9*	*4*	*3.4*	*119*	*100*
Suburban	**61**	**81.3**	**11**	**14.7**	**3**	**4.0**	**75**	**100**
Regular income	*4*	*80.0*	*1*	*20.0*		*0.0*	*5*	*100*
Business owner	*1*	*50.0*	*1*	*50.0*		*0.0*	*2*	*100*
Irregular income	*22*	*75.9*	*5*	*17.2*	*2*	*6.9*	*29*	*100*
Agriculture	*34*	*87.2*	*4*	*10.3*	*1*	*2.6*	*39*	*100*
Urban	**24**	**53.3**	**19**	**42.2**	**2**	**4.4**	**45**	**100**
Regular income	*12*	*54.5*	*9*	*40.9*	*1*	*4.5*	*22*	*100*
Business owner	*4*	*40.0*	*6*	*60.0*		*0.0*	*10*	*100*
Irregular income	*8*	*61.5*	*4*	*30.8*	*1*	*7.7*	*13*	*100*
Agriculture	*0*	*0.0*		*0.0*		*0.0*	*0*	
Total-regular income	***17***	***58.6***	***11***	***37.9***	***1***	***3.4***	***29***	***100***
Total-business owner	***5***	***41.7***	***7***	***58.3***	***0***	***0.0***	***12***	***100***
Total-irregular income	***34***	***70.8***	***11***	***22.9***	***3***	***6.3***	***48***	***100***
Total-agriculture	***142***	***89.9***	***11***	***7.0***	***5***	***3.2***	***158***	***100***
Total-all households	**198**	**80.2**	**40**	**16.2**	**9**	**3.6**	**247**	**100**

Table 7 Numbers and percentages of households that acquired biomass in different ways for Agriculture and Irregular income.

Acquiring biomass	Agriculture		Irregular Income		Total	
	No.	%	No.	%	No.	%
Collecting *(for free)*	**142**	**89.9**	**34**	**70.8**	**176**	**85.4**
Own land (paddy, upland, residential)	*99*	*62.7*	*8*	*16.7*	*107*	*51.9*
Neighbor	*1*	*0.6*	*1*	*2.1*	*2*	*1.0*
Public land	*7*	*4.4*	*13*	*27.1*	*20*	*9.7*
Own land+Neighbor	*1*	*0.6*	*2*	*4.2*	*3*	*1.5*
Own land+Publicland	*33*	*20.9*	*8*	*16.7*	*41*	*19.9*
Neighbor+Publicland		*0.0*	*1*	*2.1*	*1*	*0.5*
Own land+Neighbor+publicland	*1*	*0.6*	*1*	*2.1*	*2*	*1.0*
Buying	**11**	**7.0**	**11**	**22.9**	**22**	**10.7**
Collecting+buying	**5**	**3.2**	**3**	**6.3**	**8**	**3.9**
Own land+Buying	*3*	*1.9*	*1*	*2.1*	*4*	*1.9*
Neighbor+Buying	*1*	*0.6*		*0.0*	*1*	*0.5*
Publicland+buying		*0.0*	*1*	*2.1*	*1*	*0.5*
All combinations	*1*	*0.6*	*1*	*2.1*	*2*	*1.0*
Total	**158**	**100.0**	**48**	**100.0**	**206**	**100.0**

Table 8 Numbers and percentages of households that acquired biomass from different sources for three communities.

	Own land								**Neighbor**		**Public land**						**Purchased**		**Total**	
	Paddy		Upland		House Plot		**Total**				Forest		River forest		***Total***					
	No.	%	No.	%	No.	%	***No.***	*%*	***No.***	*%*	No.	%	No.	%	***No.***	*%*	***No.***	*%*	No.	%
rural	108	85.0	67	9.4	11	1.5	***108***	***85***	***5***	***3.9***	28	22.0	2	1.6	***28***	***22.0***	***13***	***10.2***	127	100
suburban	30	40.0	11	2.7	15	3.6	***30***	***40***	***7***	***9.3***	33	44.0	16	21.3	***33***	***44.0***	***13***	***17.3***	75	100
urban	0	0.0	0	0.0	21	8.6	***21***	***47***	***3***	***6.7***	9	20.0	1	2.2	***9***	***20.0***	***19***	***42.2***	45	100
Total	138	55.9	78	5.7	47	3.4	***159***	***64***	***15***	***6.1***	70	28.3	19	7.7	***89***	***36.0***	***45***	***18.2***	247	100

3.4 Case studies of selected households that are self-sufficient in producing all their own biomass energy

This section presents some short case studies of households that are able to get all of the biomass that they need throughout the year from their own land. These cases show the different sources of biomass on their land and describe the different approaches they use for management of these resources. They also suggest that it is possible to promote the use of biomass without forest destruction.

Case 1:

There are 4 members in this three generation household. They are 63, 56, 33 and 6 years old. The main occupation of this household is farming but the daughter works for daily wages in a factory.

They cultivate 2 plots of land with a, total land area of 2.7 ha including a paddy field of 1.6 ha and an upland field of 1.1 ha that is planted with sugarcane. Their fields are located about 1 km from the community. They go to their fields by motorcycle or in a cart pulled by an iron buffalo. On their land, they have kept a lot of the forest trees [*Plerocarpus macrocarpus* 30 trees, *Barringtonia acutanguls* (L.) *Gaertn.* 10 trees, one of *Xylia xylocarpab* (iron wood), three of *Tectona grandis L.f.* (Teak), and one of *Acacia auriculaeformis*]. They have also planted fruit trees such as *Mangifera indica* (mango) 35 trees, and tree producing edible leaves and flowers -- *Cassia siamea* 6 trees, and one sweet Tamarind. They prune the mango branches for use as fuelwood and also collect some wood from dead branches of their forest trees. These forest trees are not cut down for firewood because they want to retain them in their fields. Whenever they collect a large enough quantity of wood, they convert it into charcoal at their field, after then it is packed in a big bag and transported it to store at home.

They have enough fuelwood to meet their own needs and some surplus to share with their relatives. This household still consumes firewood and charcoal because it can be easily collected from their farm, and they can manage firewood production without much difficulty. They use about 1,200 kg per year so they are one of the highest usage households. They have no LPG stove. In the future, if wood becomes difficult to collect and acquire they will buy it for household consumption, since they believe that even if they pay for firewood or charcoal, it will still be cheaper than LPG. Anyhow, they manage their farm to ensure that they will have firewood and charcoal to use in future years.

Case 2:

This interesting case features a small agricultural household with three members: the head of household is a 60-year old man, 55-year old wife and an young boy, age 14 (student). The head of household had an operation on his back and has been bedridden for 4 months. This year, they may not be growing rice because they have no labor. At present time, the wife's daily wages comprise the main income for the household.

They own one plot of land, 1.76 ha of paddy land. The paddy field is located about 1 km to the north of the village. A small natural river runs through their land. The family works their land with an iron buffalo. There are no forest trees, but they have grown 200 Eucalyptus trees around a farm pond, along with 2 mangoes.

This household still consumes only firewood and charcoal for cooking. They have no LPG stove, both because they are afraid of the LPG explosion risk and because the initial cost of the stove and ongoing fuel costs for LPG are too high. The teenage boy prepares fires from wood that he can easily collect from their farm. This household can also ask for assistance from relatives, since there is strong cooperation between relatives and neighbors in this community. They use about 1,080 kg of wood per year, placing them in the high ratio of biomass by total. Wood management is not too complex, and fuelwood is generally collected by the last woman or boy who goes to the field. Usage is limited by the fact that they can only collect and store 2-3 weeks worth of wood at a time. They said that in the near future, the Eucalyptus trees will be enough for their household energy.

At the present time they can find wood and manage trees for household energy, and while it is not easy as in the past, trees are abundant. When wood is lacking, relatives provide assistance. In the future, if they must buy it, they will do so grudgingly, since collection of firewood has always been simple in the past. The head of household explained that even though his nephew was from a new generation, he preferred to use firewood.

Case 3:

This household has three generations. There are 5 persons, 90, 87, 50, 50 and 26. The main occupation is farming and their main income comes from agricultural and daily labor. The nephew is studying in university and has not yet graduated.

They have one plot of land of 4.9 ha comprised of 1.5 ha for paddy, 2.5 ha for sugarcane, 0.8 ha for cassava, and 0.1 ha for a farm pond in the paddy area. At the paddy area, there were formerly 12 large *Barringtonia acutanguls (L.) Gaertn.* trees which grow naturally but 10 of these trees were cut and used to build a new house. They have also planted fruit trees around pond, including 10 *Mangifera indica* (mango) trees, five *Artocarpus heterophyllus* trees, 2 coconut trees, and one each of Tamarind and *Zizyphus mauritiana Lamk.* There are ten Eucalyptus trees on the paddy bund. These trees supply sufficient biomass energy for this household. Some of the wood is shared with other adult children now living in separate households.

They use a mix of firewood and charcoal for cooking. Sometimes, when they are rushed for time, they use LPG. Almost all of the wood comes from trees in their paddy field. They consumed about 720 and 480 kg per year, of firewood and charcoal, respectively, which indicates a very high ratio of biomass by total.

The grandfather and grandmother said that they still prefer firewood consumption because it is free and is a part of their daily routine. They can easily collect and manage consumption on their own land. When enough wood is collected, they will make charcoal, normally at their paddy. He said that one of *Barringtonia acutanguls (L.) Gaertn* has supplied 5 years' worth of firewood for household energy use. They use small, residual pieces of wood to build a house right now. If their grandchildren want to change to another choice of energy, it is their decision, but for them, the first choice is firewood.

Case 4:

The head of this household is a 51 year old man who is a community leader. His wife (age 55) is a housewife, and his daughter and son-in-law are 30 year old farmers. Two granddaughters, who are students, are 12 and 5 years old. The main household income is from the paddy field, vegetables (tomato seeding production) and sugarcane.

They own 2 plots of cultivated land, with a total area of 7.6 ha, 2.8 for paddy, 4.8 ha for upland crops, and 0.5 ha for intensive tomato production (in the dry season that after rice harvesting). The total amount of firewood and charcoal consumed in this household is about 730 and 720 kg per year, respectively, but the ratio of biomass energy usage is not too high, only about 51%. Household members are quite busy, with many activities already described as well as silk production, cooking 2 meals of food for the temple every day, and travel to take good care of the villagers. All these activities consumed more energy than is typical for other households. Despite having little free time, they still mostly use firewood and charcoal for cooking, which the daughter or son-in-law collects from their own land. It is not complicated to collect and manage. The wife usually uses firewood for boiling silkworms, but sometimes uses charcoal. She makes silk every 2 weeks.

Their choice is biomass because of it is not difficult to find and it is sufficient. Sometimes they buy charcoal for silkworm boiling, depending on the time limit.

Case 5:

There are 6 members in this household, a cluster type of household characteristic of Thailand, with aged 84, 76, 55, 45, 23, and 17 years old. The main occupations of this household are the agricultural work and daily wage labor provided by the husband and wife. Her older son is a recent college graduate and is looking for work.

This household owns one plot of land with a total area of 5.6 ha: 4 ha for paddy and the remainder including 0.16 ha of tomato and 1.6 for upland crops (rotating between sugarcane and cassava). It is about 4 km to the north of the community. There are two trees of *Artocarpus heterophyllus Lam*, and one of *Schleichera trijuga*. However, wood is collected from the upland field area, where there are 8 *Pterocarpus macrocarpus*, 2 *Mangifera indica*, and one Tamarind. There is one farm pond in the upland area and about 10 Eucalyptus trees around edge of the pond. They consume about 1,200 kg of firewood and 500 kg of charcoal per year. A big stack of firewood is stored at their house, including mango, rain tree and Eucalyptus wood. The wood came from their upland fields, public lands, land of relatives and neighbors, or was purchased. A small amount came from their paddy field. They make charcoal by themselves, yielding about 200 kg. per time. This house has no LPG stove, and they cook outdoors on a firewood stove. Their lives are not rushed, and everyone in this household can collect wood for fuel. However, this year the wife bought firewood because she and her husband had no time to collect it while she was caring for her ailing father. However, buying wood is not prohibitively expensive.

They consume firewood and charcoal because they are accustomed to using low-cost, naturally occurring items. They believe that LPG is too expensive, and that is reason they do not want to use it. Firewood is still easy to collect, and although it is less abundant than it was five years ago, it is still available and there is good cooperation in the village. The wife said that some households shift to use LPG and then do not go back to using firewood because it is more convenient. For her case, the switch to LPG may not happen within the next 5 years because of its high price.

Case 6:

This is a large household with 6 people. There are 80, 67, 45, 45, 23, and 18 years old. The grandparents are aged, but still make fishnets. The main household income comes from agricultural and wage labor by the daughter and her husband. His niece has graduated from university and is looking for job. The nephew is a student.

Grandfather has 3 children and has divided his land among them. The youngest daughter who lives with him received 3.2 ha. It is the upland area with not enough water, leading them to decide to grow cassava and sugarcane, along with small amount of paddy for household consumption. There is one irrigation pond.

There are 6 tamarind trees, 2 of which are very big and old, on their land. They use tamarind wood for household fuel by cutting the branches, collected and brought to the house by the son-in-law. They consumed high ratio of biomass (85%), roughly 672 kg. per year. Wood management by cutting Tamarind branches is not difficult and is sufficient for household use.

They have previously used LPG but stopped using it because of the high price and shifted back to firewood. Although the grandchildren use firewood, in the future they may change to electricity. Still, at the present time for his household, firewood is easily acquired from their land. If it is difficult to find, they may grow 4-5 Eucalyptus trees around the farm pond or along the paddy bund. The grandfather had talked with other households who followed this practice, and he believed it would not be difficult to follow.

Case 7:

This big household is comprised of 7 people. Old generation (75 and 76 years old), wife and husband are 50 and 55 years old, and new generation are three people (29, 24, and 18 years old). Household occupations are agriculture and daily wage labor.

They have one plot of land 2.56 ha. in size and located 1 km south of their house. The land is planted with rice in the rainy season after which they plant tomatoes. There are no more trees in paddy field. They consumed large amounts of firewood and charcoal, 1,008 kg and 672 kg per year, respectively. The ratio of biomass to total energy is 83%. The son-in-law collects wood from relatives' land, transporting it by iron buffalo. They make charcoal at their land, where it is packed into bags and shared among relatives. The main reason of using wood is because it saves money and they are accustomed to using it. As long as firewood is less expensive than LPG, then their choice is wood.

Nowadays, wood is not scarce. Though it is not abundant as in the past, there is enough to use for the next 10 years. He may buy wood or plant Eucalyptus trees in order to sell or use small branches for household fuel.

Case 8:

This household has 5 members, with aged 55, 53, 30, 12 and 6 years old. The father is a farmer, and the mother stays at home. Their daughter works as an administrative officer. Their main income is from agriculture.

They have only 1.8 Ha.: 0.8 ha. for paddy, 0.16 ha. for pond and the rest for sugarcane. They have grown 100 Eucalyptus trees around a pond. The wood can be sold during the next year; the small branches will be the firewood used in their household. They did not consume much firewood (about 400 kg per year), and it is for cooking, along with LPG. They use small pieces of Eucalyptus wood obtained from the brother in law who works as a middle man collecting Eucalyptus for sale. They use LPG during the rush time, based on guidance from her daughter, because of cleanliness and convenience.

She said that for the next year, she would sell Eucalyptus trees and the small pieces will be the firewood.

Case 9:

This household has 6 people. There are, the first generation (74 and 64 years old), the second is 37 and 35 years old which works in college as a teacher, and the third are two small children.

They own one plot of paddy, 3.16 ha. in size. There are 30 Eucalyptus trees growing along a small natural river, as well as one rain tree. Around one pond, they grow vegetables. They consumed a large amount of firewood and charcoal, measuring 2,016 and 864 kg per year, respectively. The ratio of biomass is 83%. They collect wood from forested land that belongs to his older daughter. Some of the wood comes from dead trees which the son collects along the road and then takes home for storage.

They have used LPG, but stopped using it because of the cost. In the last few years, wood has been plentiful and easy to obtain. They may continue to use firewood or charcoal for the next 5 years.

Comparison of the case study households

Table 9 summarizes key characteristics of the nine case study households. Although the sample is too small to permit detailed analysis, a number of general relationships are evident. Consumption of fuelwood per capita ranges from 80 to 1,087 kg,yr, with the majority of households using a moderate quantity of between 300 and 744 kg/capita/yr. Even so, less than half of the households are currently able to produce sufficient wood on their own land to meet their consumption needs but all but two households expect to increase wood production in order to achieve self-sufficiency within the near future and have already taken steps to do so by planting Eucalyptus trees. No clear relationship between area of land per capita and self-sufficiency is evident although households that are presently self-sufficient mostly have larger per capita land areas than households that fail to produce enough wood to meet their own needs. Most households that are self-sufficient now or expect to be self-sufficient soon already have an area of trees of 0,2 ha or larger, which is the minimum area that is estimated to be necessary to sustainably produce an adequate supply of wood to meet average consumption requirements. The ratio of area covered by trees to total land area is mostly quite low, except in the case of households that have planted large numbers of Eucalyptus as a cash crop. Therefore, if households want to achieve complete self-sufficiency it appears that they have enough land available to meet their goal. The fact that several households are still able to meet their fuelwood needs by acquiring surplus wood from relatives or neighbors may reduce the urgency they feel in trying to achieve self-sufficiency.

Table 9 Summary of characteristics of case study households.

Case	Size of hh	Biomass consumed (wood equivalent) (kg./yr)		Area of land cultivated (ha)		No. of trees		Type of trees			Estimated area occupied by trees (ha)	Ratio of area of tree to total area	Self-sufficiency in fuelwood production	
		per hh	per capita	per hh	per capita	per hh	per capita	Timber	Multi-purpose	Fast-growing			Now	Future
1	4	1,200	300	2.70	0.68	90	23	47	43	-	0.41	0.15	yes	yes
2	3	1,080	360	1.76	0.59	202	67	-	2	200	0.40	0.23	no	yes
3	5	3,222	644	4.90	0.98	39	8	12	17	10	0.20	0.04	yes	yes
4	6	4,483	747	7.60	1.27	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	na.	yes	yes
5	6	3,807	634	5.60	0.93	24	4	9	5	10	0.11	0.02	no	no
6	6	2,694	449	3.20	0.53	6	1	-	6	-	0.19	0.06	yes	yes
7	7	4,511	644	2.56	0.37	2	0.3	-	2	-	0.02	0.01	no	no
8	5	400	80	1.80	0.36	120	24	-	-	120	0.24	0.13	no	yes
9	6	6,520	1,087	3.10	0.52	31	5	1	-	30	0.09	0.02	no	yes

4. Discussion

This study found that biomass energy still plays an important role as a source of energy for household consumption in communities at varying points along the rural-urban continuum. Total average energy consumption per household increased with urbanization, from 46,042 MJ/hh/yr in the rural community to 52,465 MJ/hh/yr in the suburban community to 55,076 MJ/hh/yr in the urban community. More than 90 % of all the households in the three communities used biomass at least on occasion as a source of energy, while only 9.2 % did not use biomass at all for their household energy. In the rural community, biomass energy accounted for 47.1 % of the total energy consumed by an average household but its share declined to 35.4 % in the suburban community, and to only 9.9 % in the urban community. The amounts of biomass energy used also declined with urbanization averaging 21,691, 18,557 and 5,433 MJ/hh/yr for the rural, suburban and urban communities, respectively. This finding is in agreement with other studies (Pohekar et al., 2005; Cai and Jaing, 2008; Dhingra et al., 2008) and supports the general belief that biomass energy will become less important as rural communities become more urbanized. However, the share declined only slightly when going from the rural community (47.1 %) to suburban community (35.4 %) but declined more sharply when going from the suburban to the urban community (9.9 %). These results clearly show that, biomass energy still plays a very important role for rural and suburban households and continues to play a somewhat reduced, but not insignificant role for urban people.

All of the households in three communities have easy access to all types of modern energy (e.g., electricity, LPG, gasoline, and diesel) but they differ with regard to obtaining biomass energy. Most urban people lack sufficient land to grow their own fuel wood so they either have to collect it from public land or unused lots of neighbors or purchase firewood and charcoal from rural producers at a cheap price. Rural and suburban villagers can either grow fuelwood on their own land or, if their houses are located close to the river forest and the public forest, are able to freely collect dead branches there but are prohibited by law from cutting down living forest trees. Even though they have easy access to abundant supplies of biomass energy, some households in the three communities mostly use electricity and LPG for living activities because they lack the time collect wood. Lifestyle changes also have an important influence on biomass use. Households with an urban type lifestyle, even if located in the rural village, consume less of biomass energy but more of non-biomass, whereas rural lifestyle type households use more biomass energy than non biomass energy, even if living in suburban or urban communities.

Households were classified into different groups, both within the community and across the three communities, based four factors: 1) occupation, 2) size of household, 3) level of income and 4) area of fields cultivated.

1) Four occupational groups were identified, i.e., households having regular income, having their own business, having irregular income, and making their living from agriculture. Regular income households are those who have members who receive a monthly salary as employees of government offices or private enterprises, while irregular income households have members who work for daily wages.

2) Households were assigned to three groups based on size: small (<3 persons), medium (3-5 persons) and large (>5 persons).

3) Households were also assigned to three groups according to income, i.e., below poverty line (<439 US$/yr), medium (439-3,864 US$) and well-off (>3,864 US$).

4) Households were also assigned to four groups based on the area of land they cultivated, i.e., very small (0-1 ha), small (1-2 ha), medium (2-4 ha) and large (>4 ha).

Pearson correlation of these groups with total energy, biomass energy, firewood and charcoal consumption were tested and it was found that differences among the groups were significant but the correlations were very weak. Testing for biomass and these factors are found the correlation at .34, -.33, .27 and -.21 of land area, occupation, household size, and household income, respectively. The correlation testing of household size and household income found significant differences, which is in line with the study of Cai and Jiang, 2008, whereas no significant difference was found for land area, which is contrary to the findings of Mahapatra and Mitchell (1999).

Of the 288 total sampled households, 94 % (272 hh) used less than 100,000 MJ/hh/yr, while 6 % (16 hh) used more than 100,000 MJ/hh/yr. These very high use households were found in all three communities but were excluded from further analysis in this study. The share of biomass energy in the total energy mix used by households also differed greatly among the communities, with an average of 47 % for the rural community, 37 % for the suburban one, and 13 % for the urban community. The regular income households and business owners used much less biomass energy than the irregular income and the agricultural households. The majority of the agricultural households were concentrated in the 26-50 % and 51-75 % biomass share classes, with the frequencies being 43.2 % and 35.8 %, respectively. The majority of the irregular income households were concentrated in three biomass share classes; the highest percentage (31.5 %) was in the 26-50 % share class, followed by 24.1 % in the 51-75 % share class and 22.2 % in the 1-25 % share class. Most of the households of business owners (61.1 %) were in the low share class of biomass (1-25 %), and a considerable proportion (33.3 %) did not use biomass at all. Similarly, for all households with regular income the share of biomass energy was less than 50% of their total household energy consumption, with 26.3 % being in the 26-50% biomass share class, 47.4 % in the 1-25 % share class, while 26.3 % did not use biomass at all (Table 4). Thus, biomass energy is much more important for agricultural households and irregular income households than it is for households with business owners and regular incomes.

There are three ways that households obtain biomass energy: 1) by collecting it, 2) purchasing it, and 3) both by collecting and purchasing it. Most households in all three communities in the share classes >75 %, 51-75 %, and 26-50 % s acquired biomass energy by collecting, being 92.3%, 87.5% and 87.6% of each of these share classes, respectively. The same pattern is observed in all three communities at different level of urbanization. This shows that the share class does not influence the way biomass energy was acquired. However, occupation appeared to strongly influence the choice of ways to obtain biomass fuel. Most agricultural households collected biomass fuel only from their own land (62.7 %), whereas households with irregular incomes obtained firewood from several different sources, including public land (27.1 %), their own land (16.7 %) or both public land and their own land (16.7 %).

The great continuing importance of biomass energy in communities at all levels of urbanization raises questions about the adequacy of wood supply and the sustainability with which it can be produced in the long-term. This study estimated that an average rural household consumed 20,434 MJ/yr of biomass energy while a suburban one used 18,454 MJ/yr. This represents the energy value of 2,362 and 2,062 kg of wood for rural and suburban households, respectively. At this level of demand, the annual fuelwood needs of a rural household could be sustainably met by the annual growth increment of 68 Eucalyptus trees while a suburban household would need only 59 trees. The area required to meet current average annual fuel wood consumption would be only 180 m^2 per rural household and 157 m^2 per suburban household. If the trees were planted in a line on the paddy bunds or property boundary lines with a spacing of 1.5 m between each trees, only 102 m of bund or boundary line would need to meet the needs of a rural household and 89 m would supply a suburban household for a year.

It does not appear likely that availability of land to grow trees is an important limiting factor on the ability of most rural and suburban villagers to sustainably meet their biomass energy needs in the long-term. The case studies provide some confirmation of this conclusion by showing that rural households already plant trees, especially multi-purpose trees and fast growing trees and they manage them to provide biomass energy to meet their own needs, while some of them even have a surplus that can be supplied to their relatives or neighbors. They also indicate that many people prefer to continue using cheap and readily available biomass energy for their living activities rather than switching to LPG.

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