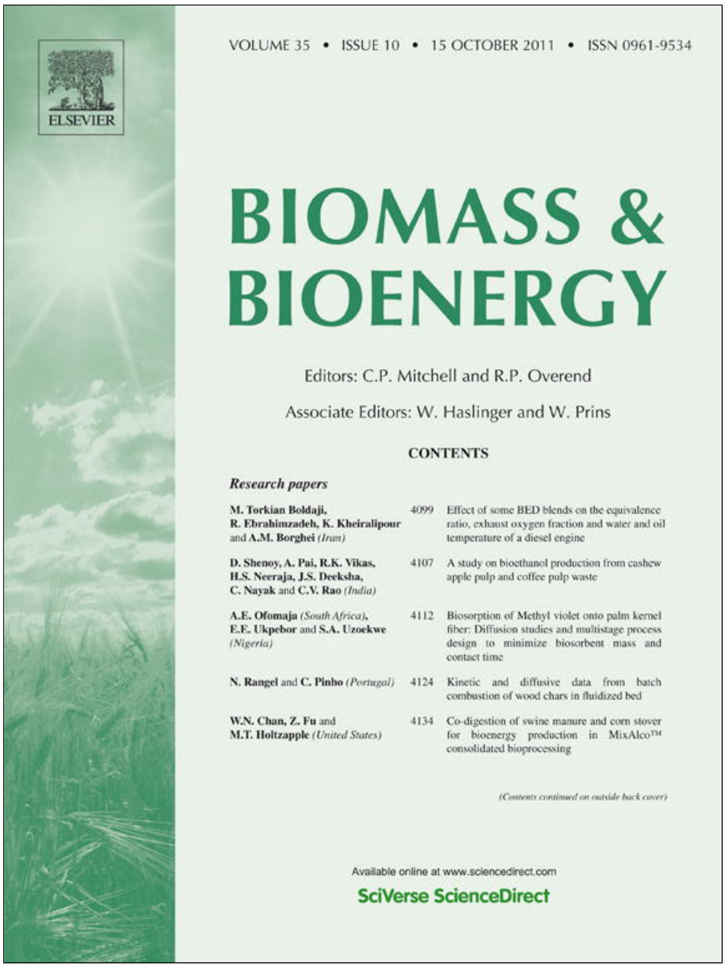
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Climbing the energy ladder or diversifying energy sources? The continuing importance of household use of biomass energy in urbanizing communities in Northeast Thailand

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ABSTRACT

Following the energy ladder model, the role of biomass energy will diminish and even disappear as rural communities become more urbanized. However, the alternative fuel stacking model suggests that, as households become more urbanized, they diversify their energy sources while continue using firewood and charcoal. This study aimed to assess the extent to which biomass energy still plays an important role as a source of energy for household consumption across the urbanization spectrum of communities. Three villages in Khon Kaen province in Northeast Thailand representing the rural, suburban and urban communities were selected for study. Data were collected on energy uses at household level using a formal questionnaire survey along with field observation and field measurement. The results showed that total household energy consumption increased with urbanization. The absolute quantity of biomass energy used slightly increased when going from rural (5.52 GJ caput^{-1} y^{-1}) to suburban (6.06 GJ caput^{-1} y^{-1}) but greatly decreased for urban community (1.98 GJ caput^{-1} y^{-1}), while the relative share declined with greater urbanization, being 46.2, 37.4 and 10.2% for the rural, suburban and urban communities, respectively. Both firewood and charcoal were used primarily for cooking, with a small amount used for home industry. It was concluded that, although the share of biomass energy in household energy portfolios does decline relative to modern energy sources in the course of urbanization, as predicted by the energy ladder model, there is no sharp discontinuity in utilization of energy sources between communities at different stages of urbanization and biomass continue to be an important component of household energy portfolios in all communities, supporting the fuel stacking model. It appears likely that biomass will remain an important source of household energy in Thailand for an extended period.

1. Introduction

It is commonly believed that, in the course of economic development, societies undergo an “energy transition” in which people choose to switch from biomass fuels to more convenient energy sources such as kerosene, liquefied petroleum gas (LPG) and electricity. This transition has been conceptualized in the form of the “energy ladder” [1]. The ladder has different rungs in different areas. For example, in South Asia, cow dung is at the bottom of the ladder, followed

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by crop residues, wood, kerosene, gas, and finally, on the top rung, electricity [1] whereas in mainland Southeast Asia, wood is on the bottom rung, with charcoal, kerosene, LPG and electricity at successively higher rungs. Fuels at each higher rung are characterized by greater convenience, cleanliness, and energy efficiency but also involve increasingly higher lifecycle monetary costs. Several factors have been found to influence these shifts in household energy consumption, including levels 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. For example, Cai and Jiang [2] reported that, in China, people living in more urbanized areas tended to use energy sources that are more convenient, cleaner, and more efficient. Studies of Indian households by Pohekar et al. [3] and Dhingra et al. [4] showed that households shifted from use of fuelwood to modern types of energy due to the recent rapid increases in the levels of urbanization, economic development, and living standards, which are accompanied by changes in the style of living and the increased access to different sources of energy with the shift toward urbanization. Even in rural areas, changes in types of energy used by households and a relative decline in the share of energy provided by biomass have been observed [5–9].

Although widely accepted, the universal validity of the energy ladder has recently been questioned by some analysts [10–13]. It has been suggested that, rather than climbing briskly up the energy ladder in the course of development, as households increase their wealth they instead diversify their energy sources, a process referred to as switching to multiple fuels or “fuel stacking”. According to this model, economically better-off urban households adopt LPG and electricity for some purposes but continue to use firewood and charcoal for others, in large part reflecting a cultural preference for food cooked with traditional methods. Certainly, contrary to expectations of the energy ladder concept, use of traditional biomass fuels (firewood and charcoal) remains quite common in many rapidly developing countries in Asia. In China, India, Lao PDR, Nepal, Pakistan, Thailand, and Vietnam, consumption of wood fuel has even increased in absolute terms [1,14–17]. Even in an economically developed country like Australia, 23% of households still used fuelwood for domestic purposes with total national consumption averaging 4.5–5.0 Mt y^{-1} [18].

Thailand offers an interesting test situation for the universal applicability of the energy ladder model. Until recently, it was a poor and mostly rural country in which farming was the dominant occupation. Almost all rural households, and even many urban ones, relied on firewood and charcoal for cooking fuel and kerosene for lighting. Beginning in the 1970s, however, the country entered a period of almost continuous economic growth. In the three decades before the 1997 economic crisis, GDP increased at an average rate of 8% annually. In the years since the economy recovered from the crisis, the GDP growth rate has averaged 4.3% per year [19]. Although income growth has been greatest in urban centers, especially the megacity of Bangkok, and in the Central Region, incomes of rural households, even in the Northeastern Region, the poorest part of the Kingdom, have also increased considerably [20]. Rapid economic growth has been accompanied by an increase in the share of the national population living in urban areas to 33%, a share that is increasing by 1.7% per year [21] along with an expansion of the middle class and the widespread adoption of “modern” lifestyles. Given these economic and social changes, it would be expected that many Thai households would have climbed up the energy ladder and largely substituted modern energy sources for the biomass energy they had traditionally employed. However, in 1990, a study of energy consumption by urban households indicated that 23.3% of households in Bangkok municipality still used charcoal and 1.2% used fuelwood while in Chiang Mai city 63% used charcoal and 16% used fuelwood [22]. Since then, there has not been any recent research on biomass energy use by households in rural and urban communities. What is needed, therefore, is empirical research to establish 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 in terms of absolute quantity used, relative share of total energy used and functional roles for which it is used.

This paper presents the findings of an investigation designed to answer the above questions that was conducted in three villages in Khon Kaen province of Northeast Thailand representing different points along the rural-urban continuum of communities, i.e., rural, suburban and urban. As the role of biomass energy in the household energy economy cannot be studied in isolation from other energy sources, households in these three communities were examined for their overall patterns of energy utilization. The objectives were to compare utilization of energy sources (biomass and non-biomass) among households in communities at different levels of urbanization in terms of absolute quantity, relative share and functional roles. Information obtained should help clarify the extent to which biomass energy still plays an important role as communities becomes more urbanized and thus test the universal validity of the energy ladder.

2. Materials and methods

2.1. *Conceptual framework*

Fig. 1 illustrates the conceptual framework for energy utilization employed in the present study. The sources of household energy are classified as biomass and non-biomass. The biomass sources are firewood, and charcoal, and the non-biomass sources include electricity, LPG, and gasoline. Household energy uses are for living, transportation, agriculture and other income generation activities. Households in the different communities are expected to differ in energy utilization, both in the absolute quantity and the relative shares of the different energy sources.

2.2. *Study approach*

Ideally, changes in household energy use in rural villages should be monitored over many years as they gradually undergo urbanization. However, such a longitudinal study is both time consuming and very expensive, and does not

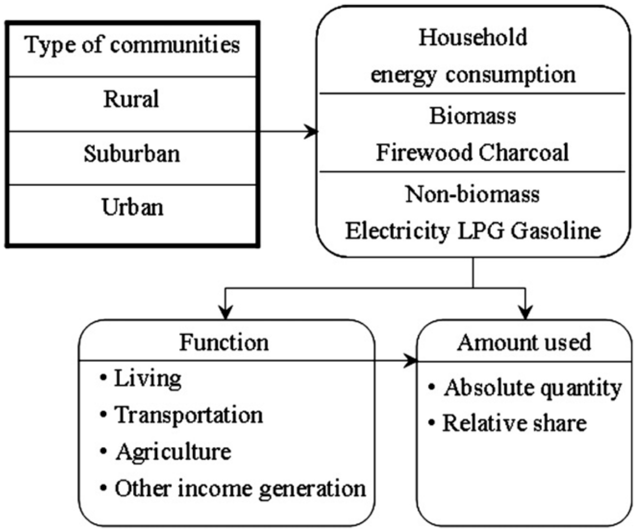

Fig. 1 – Conceptual framework for the study of household energy utilization in communities at different levels of urbanization.

provide useful results in a timely fashion. Instead, this study substituted space for time by employing a design based on studying current energy use patterns in selected communities located at different points along the rural-urban continuum. This research strategy (sometimes called the "folk-urban continuum") has been used in many studies by anthropologists [23], rural sociologists [24], and geographers [25]. This approach is based on the assumption that there is a developmental lag between urban and rural communities so that changes begin to appear first in urban areas and then gradually are adopted by nearby suburban communities before finally diffusing to more remote rural villages. The city, thus, represents the most advanced state of development, while the suburban village represents the area that has already undergone some changes in the urban direction, and the rural village represents more traditional patterns of energy use. In future years, it can be assumed that the suburban communities will continue to shift toward being more like the city while the rural villages will come to resemble the current state of the suburban ones.

2.3. *Selection of study sites*

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 (16° 25′ 60″ North, 102° 49′ 60″ East), has a population of more than 100,000 and is the sixth most populous city in Thailand [26] 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.

In selecting the three study sites that represent three points along the spectrum of urbanization in the province, the village database of 2007 [27], the Khon Kaen geo-database of 2006 [28] and the aerial photograph of Khon Kaen province in 2006 [29] were used. Twenty candidate villages were initially selected based on the distance from Khon Kaen city and the proportion of agricultural land to the total area of the community. This was followed by preliminary surveys and ground checking in candidate communities with informal interviews of key informants, selected villager groups and members of some households. Finally, Ladna Piang (16° 37′ 27.70″ North, 102° 41′ 58.56″ East), Nongbua Deemee (16° 19′ 27.34″ North, 102° 47′ 41.32″ East) and Srijan (16° 25′ 51.13″ North, 102° 50′ 36.06″ East) communities were selected to represent the rural, suburban and urban communities, respectively (Fig. 2). Additional criteria used in selecting these villages were the number of households (100–400), population density, total surface area of the community, level of infrastructure and diversity of occupation of households within the community.

2.4. *Data collection*

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, randomly selected samples of 50% of the households were interviewed and observed to record their uses of different energy sources. In the case of the urban community of Srijan, which has a smaller number of households, data were collected for all the households.

The questionnaire consists of three parts. The first part comprises information on the household, which includes name of the household head, address, number of members and their sex, age, occupation, and income earned. The second part covers number of fields they farm, area and crop grown in each field, numbers of different types of electrical appliances they use, and numbers of stoves, agricultural machines, motorcycles, and cars or trucks they own. The third part deals with the amount of energy used from each source and the activities for which that energy source is used. We measured only primary energy consumption and did not attempt to measure the energy services actually delivered to the users. The sources of energy are divided into biomass, which includes firewood, charcoal, and others, and non-biomass, which includes electricity, LPG and petroleum fuels including gasoline (used for motorbikes, most cars, and some trucks) and diesel oil (used for tractors and some trucks). The uses of energy are divided into cooking, living, transportation, agriculture and other income generation activities. The questionnaire was pretested before conducting the actual survey.

The amount 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 to be used 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.

The amount of electricity which consumed by individual households were determined from their monthly electricity

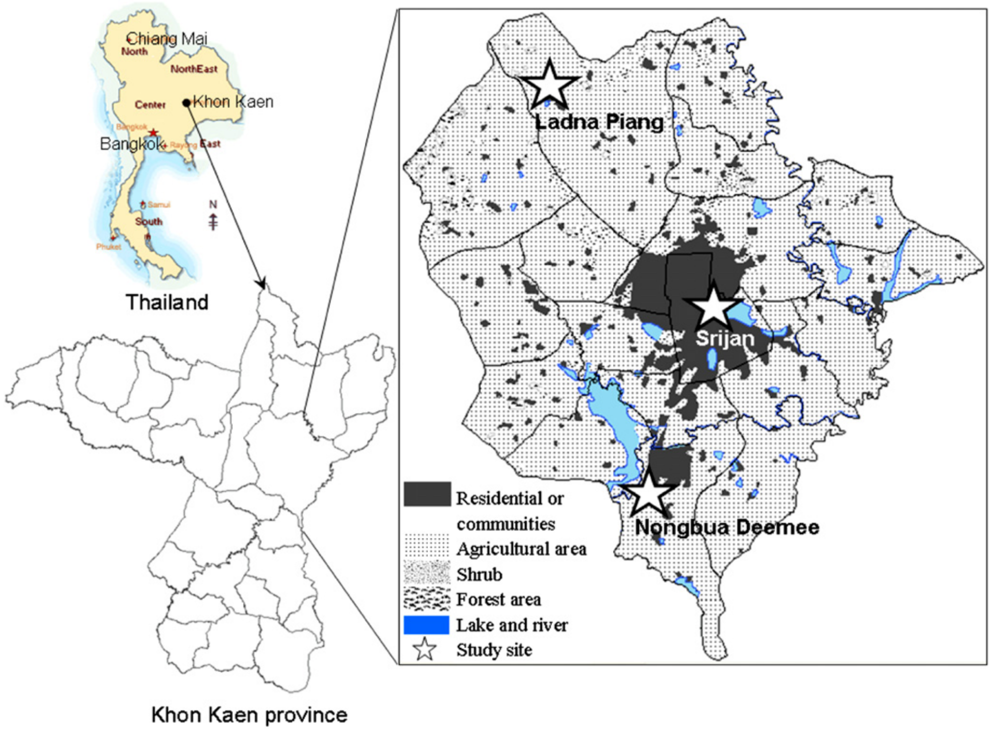

Fig. 2 – Location of the three study communities.

bills. The numbers and power rating of all electrical appliances were also observed and recorded.

The amount of LPG used by each household was obtained by asking the appropriate member of the household on how long a tank of LPG would normally last.

The amount of petroleum fuel (gasoline and diesel) used for motor vehicles (automobiles and trucks) and motorcycles was obtained by asking how much money was spent for gasoline or diesel in a month for each motorcycle and for each car or truck, and then converting to volume using the average price of gasoline during that month.

The amount of petroleum fuel used for agricultural production by a household was derived by determining the standard amount of fuel used by farm machinery per hectare for each type of crop, i.e., rice, cassava and sugarcane, and then multiplying the amount used per hectare with the corresponding planted area of that crop. Determination of the amount used per hectare for each crop was done by interviewing tractor operators and tractor dealers for each type of operation, i.e., plowing, harrowing and combine harvesting, and then summing all operations respective to the crop. The average figure over those obtained from all key informants was used as the standard amount of petroleum fuel use for a particular crop.

The amount of gasoline or diesel used for other income generating activities was collected by interviewing appropriate household members.

All the data obtained were converted into a standard energy unit (Mega Joules, MJ) for further analysis, using conversion factors obtained from the Department of Alternative Energy Development and Efficiency, Ministry of Energy of Thailand [16]. Energy conversion units used were LPG 28 MJ dm^{-3}, gasoline 31.48 MJ dm^{-3}, kerosene 34.53 MJ dm^{-3}, diesel 36.42 MJ dm^{-3}, electricity 3.6 MJ kWh^{-1}, fuelwood (dry basis) 16 MJ kg^{-1} and charcoal 29 MJ kg^{-1}. Density conversions were solid wood 600 kg m^{-3}, charcoal 250 kg m^{-3} and LPG 540 kg m^{-3}. It was assumed that the mass yield of charcoal was 200 kg m^{-3} of fuelwood.

2.5. *Data analysis*

The absolute quantities of the different types of energy and their relative shares of the total energy mix used per capita by each household were computed. These were used to calculate the average absolute quantities and their relative shares of the different types of energy used by all households in each of the individual communities. Comparisons were made among the three communities on the amount and share of energy used from different sources, and the changes in functional roles of different sources of energy with increasing urbanization were assessed. One-way analysis of variance (ANOVA) and Duncan multiple range test (DMRT) were performed using SPSS software [30] to analyze and test for statistical differences in average energy consumption among communities at different levels of urbanization.

3. Results

3.1. *Characteristics of the study communities*

The three study villages, Ladna Piang, Nongbua Deemee, and Srijan, are located in Maung district of Khon Kaen province (Fig. 2). Their characteristics are given in Tables 1 and 2.

Table 1 – Characteristics of the three study communities.

Characteristics	Rural: Ladna Piang	Suburban: Nongbua Deemee	Urban: Srijan
Distance from Khon Kaen 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^{-1})	2	22	132
Proportion of agriculture land	high = 0.97	medium = 0.72	very low
Occupational diversity	Low	medium	high
Infrastructure	Low	medium	high

Sources: Khon Kaen geo-database [28], Household database [27].

Ladna Piang, the rural village, is the least economically developed community with the lowest average household income. It is located 32 km from Khon Kaen city, and is 15 km from the main highway but connected to it by a paved road. It has the largest land area (832.5 ha), but the lowest population density (2 persons ha^{-1}) among the three villages. Most of the area (97%) is agricultural land used to grow rice, cassava, sugarcane and vegetables (Table 1). Most (93.8%) of the household heads are farmers, the rest are laborers (4.6%) and government or private enterprise employees (1.5%) (Table 2), thus, the community has low occupational diversity. The village has a day-care facility for pre-school children, primary school and junior high school, but has no health service center. All households have access to electricity, mobile telephone service, and tap water provided through the community managed system. Most of the houses are typical rural Thai wooden houses built on stilts, but there are also a few modern style masonry houses in the village. Most houses have an adjoining rice storage barn, also built on stilts, around which firewood is stored. The life style in this community is typically rural; women still engage in making handicrafts, such as silk weaving, when they are free from farm work. It should be pointed out that this community represents a "developed rural community", which is located at the upper end of the rural range in the rural-urban continuum. At present, there are no really traditional rural communities left in Thailand, except perhaps in the very remote mountain areas.

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[a]			
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[b]			
Below poverty line (<439 US$ y^{-1})	7.7	16.1	3.1
Medium (439–3864 US$ y^{-1})	65.4	60.2	40.0
Well-off (>3864 US$ y^{-1})	26.9	23.7	56.9
Average household income (US$ y^{-1})	3584	3822	7265
Average per capita income (US$ y^{-1})	846	1007	2090
Land 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 land area (ha.)	3.6	0.7	0.02

a Regular income = Monthly salary from public or private organization; Irregular income = Daily wage work. Income data were obtained from the household interview.
b 1 US$ = 33.64 Thai Baht.

At the opposite end of the rural-urban continuum is the village of Srijan inside Khon Kaen city. It is the most economically developed community and has by far the highest average per capita income level. It has the smallest land area (6.8 ha), but the densest population (132 persons ha^{-1}) of the three communities (Table 1). There is no agricultural land in this village, but there are few unused vacant plots, belonging to rich investors, that are used by some villagers to raise cattle and collect firewood. The community has easy access to all the facilities and infrastructure available in Khon Kaen city, e.g., transportation, electricity, telephone, tap water, public and private schools from primary to university level, public and private hospitals, supermarkets, shopping centers, public services, etc. Houses are of modern style, made from concrete, in the form of detached houses, townhouses and apartments. Almost half of the households (49.2%) have members who are employees of public organizations or private enterprises with regular income; the rest are more or less equally divided between business owners (26.2%) and daily wage workers (24.6%); no households have agriculture as their main occupation (Table 2). The life style is typical of residents of provincial cities in Thailand.

Nongbua Deemee, the suburban village, has characteristics that are intermediate between Ladna Piang and Srijan with regard to economic development and urbanization. It is 12.5 km from Khon Kaen city, to which it is connected by a good all weather road. The villagers, thus, can have access to all the facilities and infrastructure available in Khon Kaen city although using these services is less convenient for them than it is for households in Srijan village. Total land area (75.2 ha) and population density (22 persons ha^{-1}) is intermediate among the three communities (Table 1). Agricultural land accounts for 72% of the total community area, but many plots are not used because their owners either have other occupations or are rich people living outside the community. There are fewer agricultural households (48.4%) but more households with daily wage workers (36.6%), government and private employees with regular salaries (10.8%) and business owners (4.3%) in this village than in the rural village of Ladna Piang (Table 2), so that occupational diversity was considered as medium. There are also more houses of modern-style than in Ladna Piang, and more people follow an urban life style.

The mean size of households tended to decrease with urbanization, being 4.2, 3.9 and 3.3 persons in the rural, suburban and urban communities, respectively. Households of medium size (3–5 persons) were the most numerous class in all of the communities, but the rural community had a greater share of large (>5 persons) households, while the urban community had a greater share of small (<3 persons) households (Table 2).

Data from the household survey indicated that income increased with urbanization, with average household incomes for the rural, suburban, urban communities being 3584, 3822 and 7265 US\$ hh^{-1} y^{-1} (or 846, 1007 and 2090 US\$ $caput^{-1}$ y^{-1}), respectively (data were obtained in Thai Baht which were converted to US\$ at the rate of 1 US\$ = 33.64 Thai Baht). The distribution of households with different income levels was similar for the rural and suburban communities, with the majority (>60%) being in the medium income class, but poor households were more numerous in the suburban community. More than half (56.9%) of the households in the urban community were well-off, while 40% had medium income (Table 2).

Clearly, the area of land cultivated per household decreased with urbanization. All households in the urban community had no or very small plots of land, while the majority of the households in the rural community cultivated large and medium sized areas of land, but most of the households in the suburban community cultivated small or very small areas of land (Table 2).

Most households in all the three communities used biomass energy (Table 3). However, percentages of households using firewood were quite high for the rural (94%) and suburban (80%) communities, but much lower (46%) for the urban community, while percentages of households that used charcoal declined more gradually with urbanization, being 88, 83 and 74% for the rural, suburban and urban communities, respectively (Table 3). Conversely, percentages of households that used LPG increased with urbanization, being 48, 69 and 71%, for the rural, suburban and urban communities, respectively. All households in the three communities used electricity for their living activities. Most of the households had motorcycles, but the percentage declined with urbanization, while the share of households owning cars or trucks increased with urbanization (Table 3).

Table 3 – Percentages of sampled households using different sources of energy in the three study communities.

Source of energy	Rural: Ladna Piang (130 hh)	Suburban: Nongbua Deemee (93 hh)	Urban: Srijan (65 hh)
Biomass	98	89	78
Firewood	94	80	46
Charcoal	88	83	74
LPG	48	69	71
Electricity	100	100	100
Gasoline and diesel	97	93	71
Agriculture	88	43	0
Vehicle	92	90	82
Motorcycle	91	88	71
Car	22	24	42

3.2. *Differences in household energy consumption among communities*

Total average energy consumption, both per household and per capita, increased with urbanization, from 46.04 GJ hh^{-1} y^{-1} or 11.95 GJ $caput^{-1}$ y^{-1} in the rural community to 52.47 GJ hh^{-1} y^{-1} or 16.22 GJ $caput^{-1}$ y^{-1} in the suburban community to 55.08 GJ hh^{-1} y^{-1} or 19.40 GJ $caput^{-1}$ y^{-1} in the urban community (Table 4). The share provided by biomass energy decreased with urbanization, from 46.2% of the total energy consumed per capita by households in the rural community, to 37.4% in the suburban community, to only 10.2% in the urban community. The amounts of biomass energy used per household declined with urbanization, being 21.69, 18.56 and 5.43 GJ hh^{-1} y^{-1} for the rural, suburban and urban communities, respectively. However, the amount of biomass energy used per capita increased slightly from 5.52 to 6.06 GJ $caput^{-1}$ y^{-1} when going from the rural to the suburban community, but declined greatly to 1.98 GJ $caput^{-1}$ y^{-1} for the urban community. At the same time, the amount of non-biomass energy used progressively increased from 24.35 GJ hh^{-1} y^{-1} or 6.43 GJ $caput^{-1}$ y^{-1} for the rural community to 33.91 GJ hh^{-1} y^{-1} or 10.16 GJ $caput^{-1}$ y^{-1} for the suburban community to 49.64 GJ hh^{-1} y^{-1} or 17.42 GJ $caput^{-1}$ y^{-1} for the urban community. The increased amount of biomass energy used per capita when going from the rural to the suburban community was from the increased use of firewood, while the progressive increases in the amount of non-biomass energy as the community became more urbanized were from the increased uses of electricity for the large part and of LPG to some extent (Fig. 3). Thus, the steep drop in the share of energy provided by biomass for urban households is in part an artifact of the major increase in the quantity of non-biomass energy they use. In terms of absolute quantities, urban households continue to use one-third as much biomass energy per capita as rural households.

3.3. *The roles of different types of energy*

The roles of different types of energy were the same in the three communities, but their relative shares of total energy used varied among the three communities. For the rural community, energy used for living accounted for 56% of total household energy consumption; most of this was provided by biomass (79%), with firewood and charcoal providing almost equal shares (Table 5). The shares provided by LPG and electricity were only 5 and 6.7%, respectively. A slightly greater share of energy (61%) was used for living in the suburban community, of which biomass provided almost two-thirds (61%). Somewhat more firewood was used than charcoal. More LPG and electricity were used than in the rural community, and their shares increased to 9 and 15%,

Table 4 – Absolute quantity (Mean ± SE) and relative share of household energy consumption per household and per capita in communities with different levels of urbanization.

Community	No. of HHs	Biomass		Non-biomass		Total	
		Quantity ± SE	%	Quantity ± SE	%	Quantity ± SE	%
Average energy consumption per household (GJ hh^{-1} y^{-1})							
Rural	130	21.69 a ± 1.57	47.1	24.35 c ± 1.51	52.9	46.04 a ± 2.19	100
Suburban	93	18.56 a ± 2.00	35.4	33.91 b ± 3.31	64.6	52.47 a ± 3.84	100
Urban	65	5.43 b ± 0.99	9.9	49.64 a ± 4.66	90.1	55.08 a ± 5.77	100
Overall average	288	17.01 ± 1.05	33.9	33.15 ± 1.74	66.6	50.16 ± 1.91	100
Average energy consumption per capita (GJ $caput^{-1}$ y^{-1})							
Rural	130	5.52 a ± 0.36	46.2	6.43 c ± 0.51	53.8	11.95 b ± 0.65	100
Suburban	93	6.06 a ± 1.16	37.4	10.16 b ± 1.12	62.6	16.22 a ± 1.73	100
Urban	65	1.98 b ± 0.36	10.2	17.42 a ± 1.87	89.8	19.40 a ± 1.88	100
Overall average	288	4.90 ± 0.43	32.6	10.11 ± 0.65	67.4	15.01 ± 0.78	100

Different letters in the same column indicate statistical difference at P = 0.05 by DMRT.

respectively. For the urban community, energy for living was about half (55%) of total energy use, with electricity providing the largest share (65%), LPG providing 16%, while biomass provided almost 19%.

These results clearly show that as communities become more urbanized people tend to change the types of energy they use for living activities from biomass to cleaner sources (LPG and electricity). However, the changes were relatively slight when moving from the rural to the suburban community, but were quite pronounced when moving from suburban to urban. The use of gasoline and diesel for transportation also increased in both absolute amount and relative share with urbanization, with the share being 33.1, 39.1 and 49.7% for the rural, the suburban and the urban communities, respectively. In the rural community, petroleum fuel was used for motorcycles (60%) more than for cars and trucks whereas in the suburban and urban communities more fuel was used for cars and trucks than for motorcycles. The amount and share of energy used for agriculture and home industry both rapidly declined in the course of urbanization (Table 5).

4. Discussion

This study aimed to investigate the extent to which biomass energy still plays an important role as a source of energy for household consumption across the urbanization spectrum of communities in Northeast Thailand. This was done by comparing the energy uses of households in three villages in Khon Kaen province that were selected to represent the rural, suburban and urban points on the rural-urban continuum and examining the functional roles of biomass energy in households in these communities.

The results show that, as expected, on a per capita basis, average total household energy consumption increased considerably in the course of urbanization. This increase is in part an artifact of the decline in the average household size that accompanies urbanization, because large households tend to consume less energy per capita than small households, due to the fact that many uses of energy in household living activities are not divisible (e.g., it takes about as much firewood to steam a basket of sticky rice for a family of 6 as it does for a family with only 2 members). However, as Fig. 3 shows, the increase in total household energy consumption with urbanization was mainly came from the increased use of electricity and to some extent the increase in LPG consumption, which were more than offsetting the decline in biomass energy consumption. Data from the household survey in the present study also indicated that very small urban households (1–2 members) consumed much more energy per capita, especially electricity, than do households of comparable size in the suburban and rural communities. This was because they have a larger number of light bulbs and also more energy-hungry large appliances (e.g., air conditioners, refrigerators, hot water heaters, televisions, and computers) than very small rural households (data not shown). These evidences suggest that adoption of a modern urban life style itself also results in higher consumption of energy.

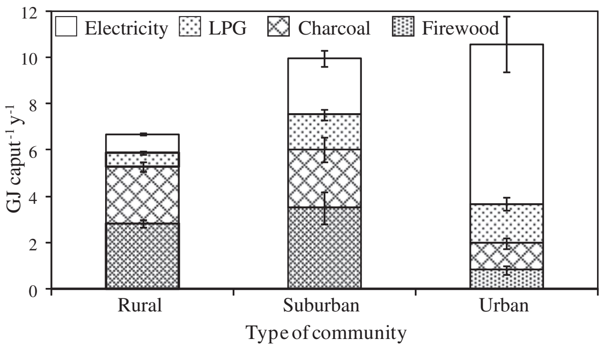

Fig. 3 – Household energy use for living activities in rural, suburban, and urban communities in Northeast Thailand. Source: Household survey in the present study.

The results also show that the roles of different types of energy were the same in the rural, suburban and urban communities, but their relative shares in the total energy mix used by households varied among the three communities. The share of biomass energy was highest for the rural community and declined with greater urbanization, while the opposite trend was observed for household uses of LPG and electricity. These results agree well with previous reports that people tend to change the source of energy for living from biomass to cleaner sources (LPG and electricity) as their communities become more urbanized [2–4,8,9]. This finding also supports

Table 5 – Energy consumption per capita (GJ $caput^{-1}$ y^{-1}) and relative share by activity and source in rural, suburban and urban communities (Mean ± SE).

Activity	Rural		Suburban		Urban	
	Amount ± SE	%	Amount ± SE	%	Amount ± SE	%
Total living	6.69 ± 0.35	56.0	9.95 ± 1.27	61.3	10.59 ± 0.85	54.6
Biomass	5.29 ± 0.31	44.3	6.04 ± 1.16	37.2	1.98 ± 0.36	10.2
Firewood	2.83 ± 0.18	23.7	3.51 ± 0.68	21.6	0.82 ± 0.19	4.2
Charcoal	2.47 ± 0.21	20.6	2.53 ± 0.53	15.6	1.16 ± 0.25	6.0
LPG	0.60 ± 0.09	5.0	1.50 ± 0.24	9.2	1.71 ± 0.28	8.8
Electricity	0.81 ± 0.05	6.7	2.41 ± 0.35	14.9	6.90 ± 1.19	35.6
Transportation-Gasoline	4.05 ± 0.45	33.9	5.99 ± 1.02	36.9	8.81 ± 1.55	45.4
Motorcycle	2.42 ± 0.20	20.3	2.78 ± 0.29	17.1	2.24 ± 0.41	11.5
Car	1.63 ± 0.38	13.6	3.21 ± 0.95	19.8	6.57 ± 1.37	33.9
Agriculture- Diesel	0.98 ± 0.10	8.2	0.26 ± 0.06	1.6	0.0	0.0
Home industry	0.23 ± 0.19	1.9	0.03 ± 0.03	0.2	0.0	0.0
Firewood	0.04 ± 0.01	0.3	0.03 ± 0.03	0.2	0.0	0.0
Charcoal	0.02 ± 0.02	1.6	0.0	0.0	0.0	0.0
Total	11.95 ± 0.65	100.0	16.22 ± 1.73	100.0	19.4 ± 01.88	100.0

the energy ladder concept according to which the role of biomass energy will decline as rural communities become more urbanized.

The results, however, also reveal that the decline in the share of biomass energy was rather small when going from the rural to the suburban community, and the absolute quantity actually increased, while even households in the urban community continued to use a considerable quantity of biomass energy, albeit this represents a low share of their much expanded total energy consumption. These results clearly indicated that although the use of biomass energy did decline with urbanization, which is in keeping with expectations of the energy ladder concept, it still continues to be an important source of household energy in both the suburban and urban communities, which is contrary to conventional assumptions about the energy transition but fits well with the fuel stacking model. In fact, an earlier comparative study of energy use by urban households in several Asian countries, the findings of which generally supported the energy ladder model [31], had found that Thai households at all income levels were exceptional in their continued substantial use of charcoal for cooking, reflecting the strong cultural preference for steaming glutinous rice and grilling meat using charcoal.

In general, households in our study, regardless of their extent of urbanization, strongly prefer to use firewood or charcoal for steaming glutinous rice (the staple carbohydrate in Northeast Thailand) whereas they use electric rice cookers on those less common occasions when they cook non-sticky rice. LPG is used for quick frying of meat and vegetables but charcoal is preferred for slow roasting or boiling of meat and vegetable dishes. Furthermore, in preparing the main meal of the day, steaming of glutinous rice is done first using firewood or charcoal, then cooking will continue with firewood or charcoal for the remaining dishes regardless of the type. It appears that fuel preferences for cooking is an important influencing factor for continuing use of biomass energy of the households despite the accessibility to other energy sources. This finding is in line with what have been found elsewhere. For example, in Mexico, it was reported that the mixed fuelwood-LPG users preferred fuelwood for making tortillas, and traditional foods that were prepared for the frequent village and family parties were also cooked with fuel wood [11,12]. For households in our study, although their uses of biomass energy may partly be for economic reason, e.g., for long cooking time, the preferred use of firewood for steaming glutinous rice is clearly a cultural preference.

In conclusion, although the results of this study are generally compatible with the energy ladder concept, in that the use of biomass energy by suburban and, especially urban households has declined, while their use of modern energy sources has greatly increased, the continuing extensive use of firewood and charcoal for cooking by well-off households in all of these communities, despite the widespread availability of LPG and electricity, supports the fuel stacking model. Although people in rural villages can be expected to make greater use of LPG and electricity in future years if the current rapid pace of economic development continues, it is also probable that they, like their already urbanized counterparts today, will persist in using firewood and charcoal for cooking many culturally favored dishes. It, therefore, appears likely that biomass will remain an important source of household energy in Thailand for an extended period.

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