

Macro Patterns in the Use of Traditional Biomass Fuels

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*Nadejda M. Victor & David G. Victor*¹

0. Introduction

About 2.4 billion people rely on traditional biomass, mainly for cooking and heating (IEA, 2002). Essentially all of those users of traditional fuels reside in developing countries, and most of them live in rural areas; low incomes and the lack of access to alternative, modern fuels explain their choice of traditional energy supply. By the late 1990s, IEA (1998) estimated that biomass accounted for approximately 14 percent of final energy consumption, roughly on par with electricity (14 percent). It is likely that the fraction of total energy supplied by biomass will decline in the future as traditional energy carriers are supplanted by the modern movers such as electricity. This paper provides an overview of that “energy transition” from traditional to commercial fuels from the perspective of available macro-economic data. Based on the long time series data available for the United States it suggests some basic patterns in the energy transition, and it examines the transition under way in several major developing countries. It offers a simple regression model of the transition and suggests topics for further research, including an improved regression model. Other papers presented at this workshop complement the analysis by examining data and theory related to the micro-level processes in villages and households. Some papers examine the policies that governments have adopted in attempts to accelerate or tailor the energy transition. A few papers also examine modeling tools that can be used to describe and predict the character of the energy transition.

Traditional biomass energy is usually defined as fuelwood and charcoal, agricultural residues, and animal dung. Because agriculture is the dominant economic activity in rural areas where most users of traditional biomass fuels reside, much “traditional” energy is associated with agriculture—in essence, it recycles agricultural byproducts (animal dung and crop residues, especially) to useful energy for the household. Where available, non-agricultural sources of energy—such as forests—also contribute to energy budgets, mainly in the form of cut wood and charcoal. Collectively, these many sources of energy travel under many labels, including “biomass fuels” (or “biofuels”); “non-commercial energy”; “traditional fuels”; “rural energy”; “combustible

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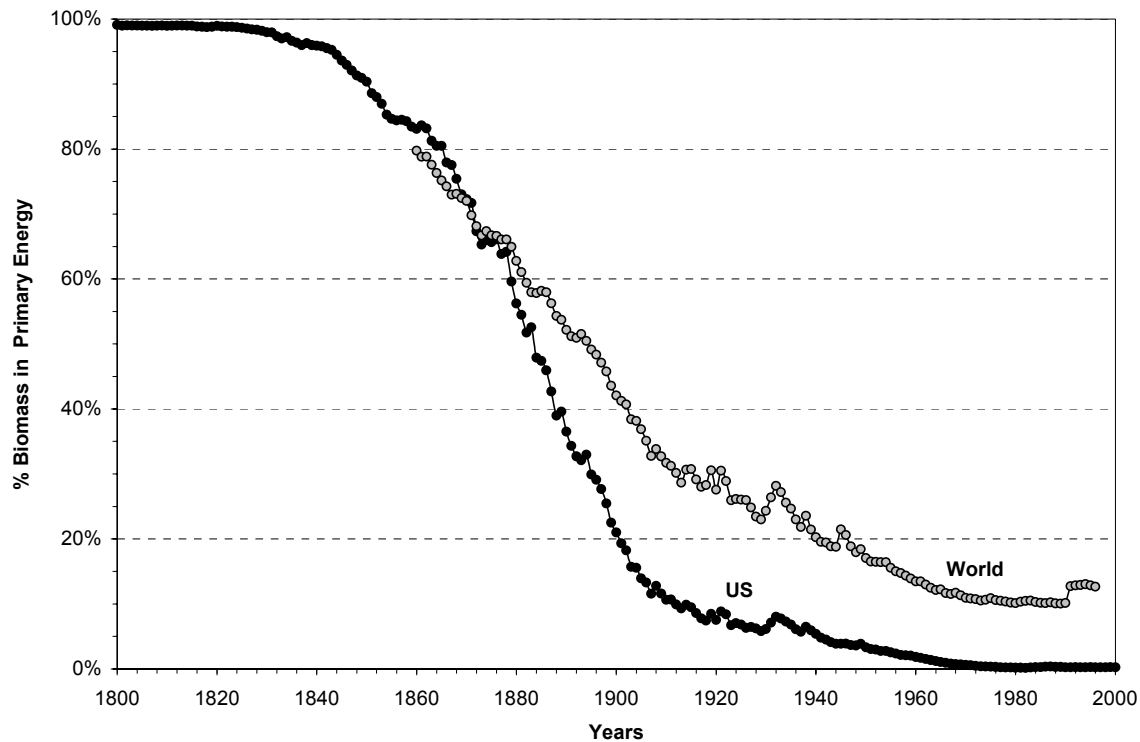


Figure 1. Share of Biomass in Primary Energy Mix for the US (1800-2000) and for World (1860-1996). Source: Nakićenović et al. (1998), UN, EIA (2002)

renewables and waste (CRW)”.² None of these labels is ideal. It is incorrect to equate biomass with non-commercial fuels, as a large and increasing share of fuelwood and practically all charcoal are traded in commercial markets. The term “traditional” is confusing because the same fuel (e.g. fuelwood) can be used in a traditional three-stone cooking ring or in a modern industrial boiler to generate electricity or heat. The term “rural energy” is also confusing—although biomass energy is mainly used in the rural household sector; it also provides an important fuel source for traditional village-based industries. Moreover, in some cities traditional fuels imported from the countryside account for a large share of household energy budgets—notably, charcoal and firewood. Mindful of the terminological swamp that bogs down any discussion of this topic, in this paper we focus on the concept of “traditional biomass” and, where possible, we illustrate how our results vary with the concept.

We begin with attention to historical patterns in the United States and identify a few key patterns. Then we shift to today’s developing countries.

² Combustible renewables & waste is IEA’s definition biomass energy that comprises solid biomass and animal products, gas/liquids from biomass, industrial waste and municipal waste.

II. Patterns in History: U.S. Example

Assessing patterns in the role of traditional biomass in today's developing economies is a difficult task, but some patterns and images of the future are evident by looking at history in the countries that have long time series data. During the pre-industrial age and through the industrialization period, traditional biomass played a significant role for all countries now known as developed countries.

Figure 1 shows the share of traditional biomass in primary energy mix in the US in 1800-2000 and at the global level (1860-2000). The data confirm the expectation that the share of traditional biomass in primary energy consumption declines steadily with development - from 99 percent at the beginning of the observed period to 0.2 percent in 1998 in US and from 80 percent to 13 percent at the global level. The period of rapid reduction could be observed through 60 years (in 1850-1910), the period of industrialization when coal substituted for traditional biomass and became the most important fuel for industrial production.

The share of coal increased rapidly since 1850 and reached 50 percent of total primary energy in 1885 (see Figure 2). On a per-capita basis, biomass consumption increased in the US until 1830, the earliest stage of the industrial revolution, and then decreased constantly with growth in income (Figure 3). The most rapid decrease of biomass per capita consumption can be observed during the period of rapid industrialization.

Although the share of biomass in the energy system declined, the absolute quantity of biomass consumed in the United States continued to increase until 1870. Thereafter both the share and absolute quantity decreased steadily as the process of industrialization caused switching away from inflexible, low power density wood (Figure 4). The cause of this initial increase in total consumption of traditional biomass fuels in the early decades of industrialized is probably the slow pace in changing energy infrastructures (Grübler et al., 1999). In the early period of industrialization in US, biomass energy was used for industrial process and for households in urban areas. The extra income of industrial growth allowed purchase of additional energy services, and for a generation those services still included traditional biomass.

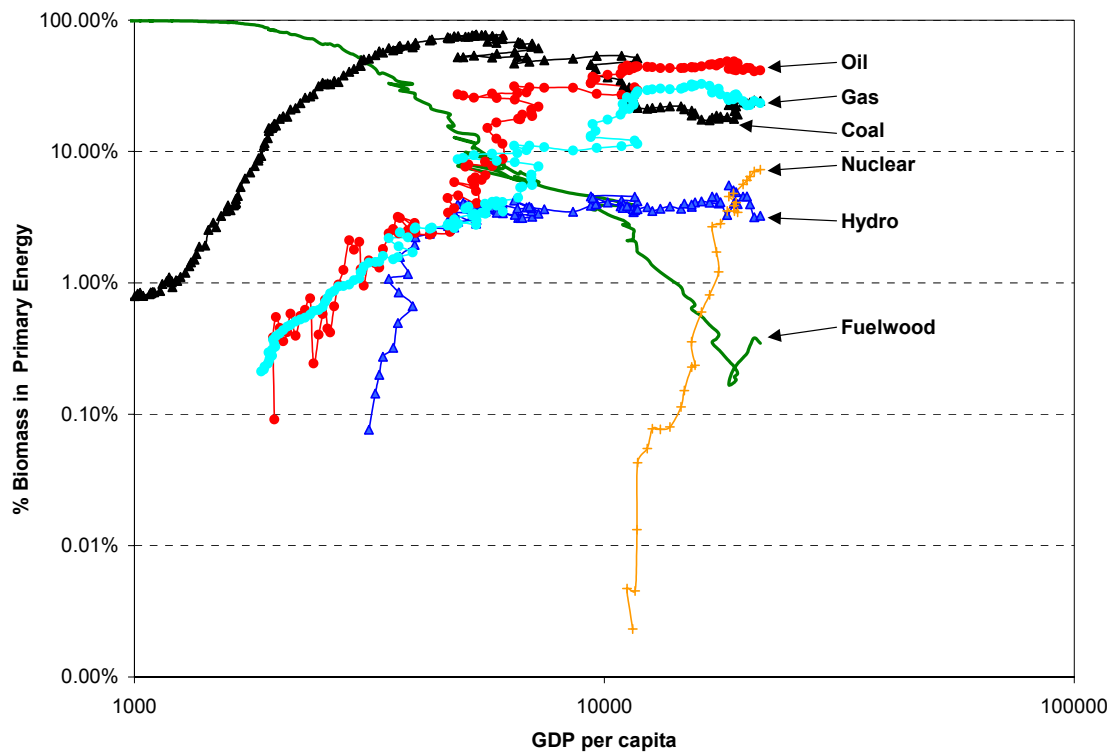


Figure 2. USA: Primary Energy Mix versus GDP per capita, 1800-2000. Source: Nakićenović et al. (1998), EIA (2002), BEA (2002)

Until 1870 much economic growth had been more or less extensive in nature, associated with the cultivation of new lands and their integration into the national economy. Rural development came with its own new resources and generally led to high levels of energy consumption relative to urban energy use. After 1870, as the rural frontier in America closed, growth was increasingly intensive and transformational. Agricultural productivity rose—making more productive use of increasingly scarce lands—and economic activity shifted from the farm to the city, from the cultivation of crops to the factory production of manufactured goods. Figure 5 illustrates this process through logistic curves.

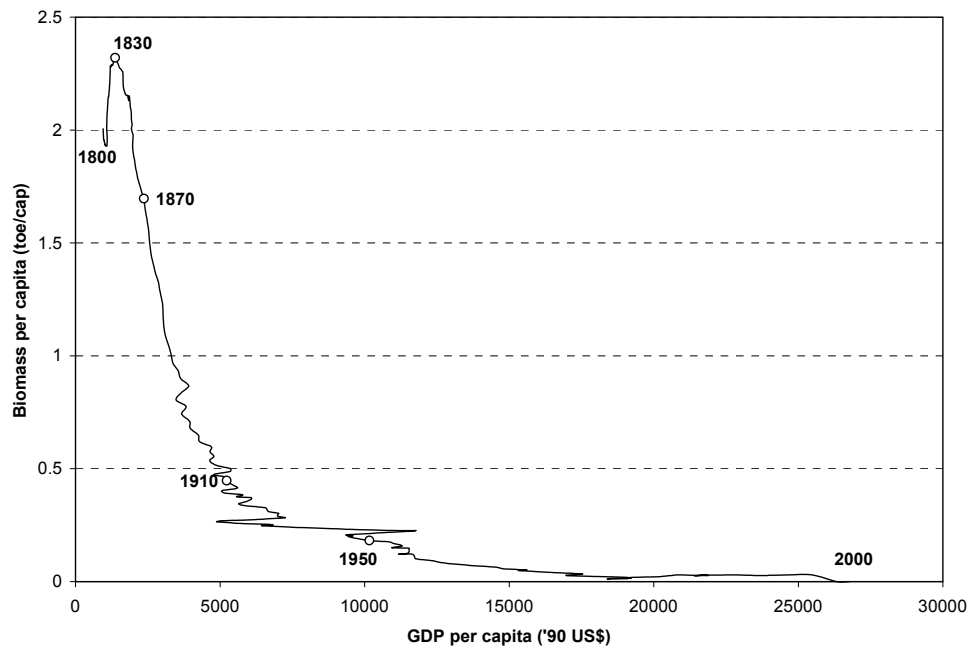


Figure 3. USA: biomass per capita consumption versus GDP per capita, 1800-2000. Data source: Nakićenović et al. (1998), EIA (2002), BEA (2002)

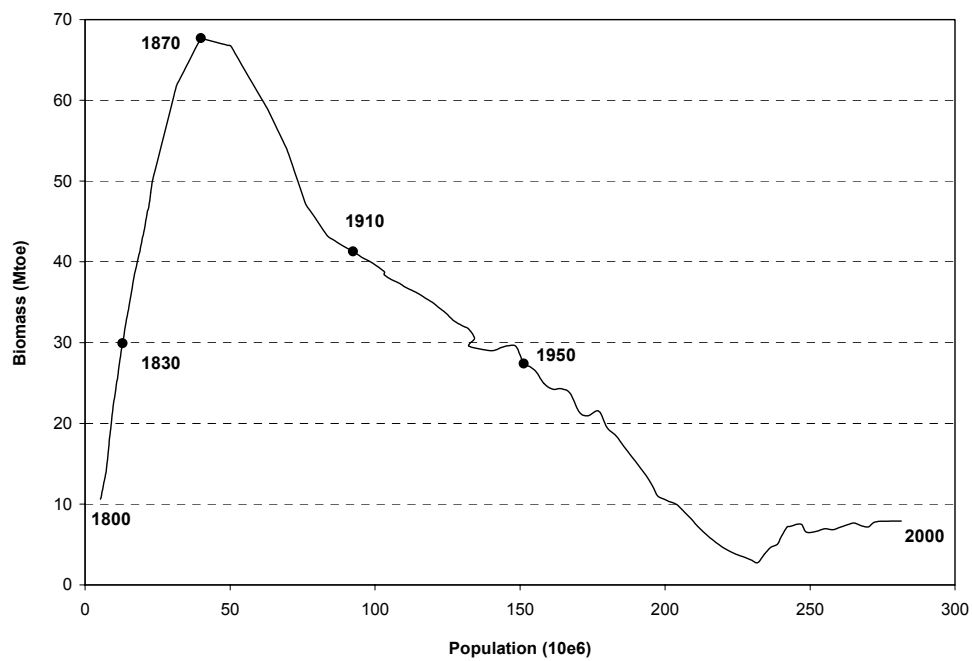


Figure 4. USA: Biomass energy consumption versus population, 1800-2000. Source: Nakićenović et al. (1998), EIA (2002), BEA (2002)

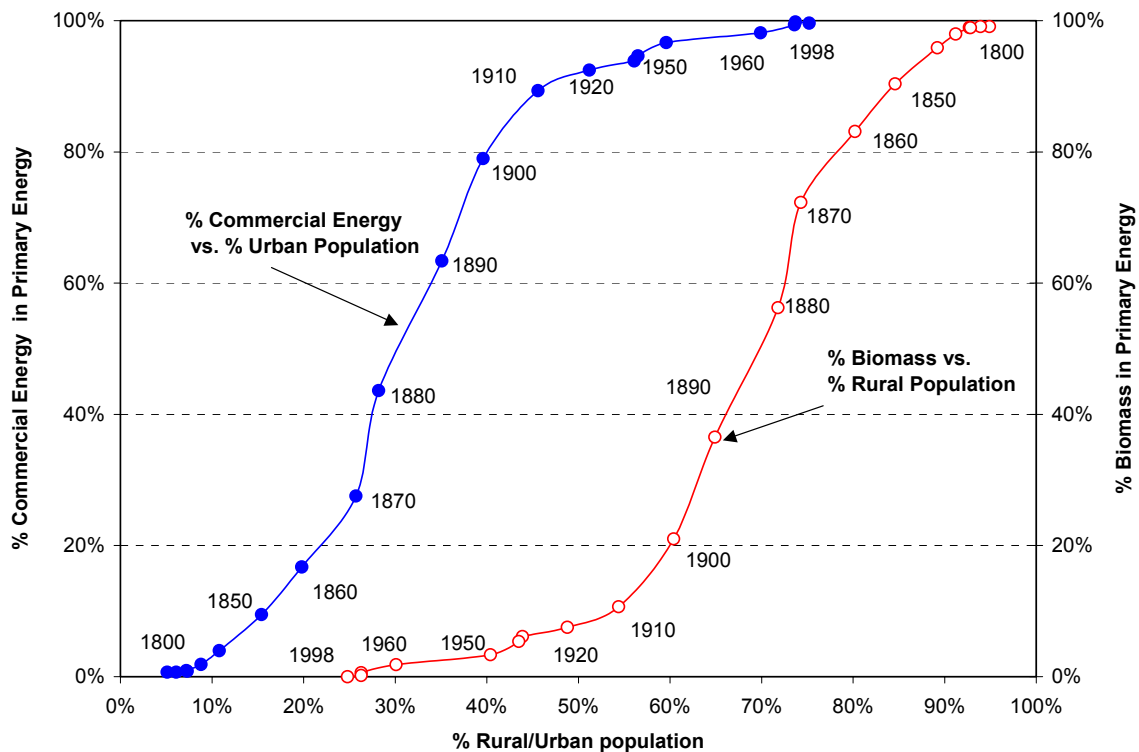


Figure 5. USA: Share of Biomass in Primary Energy Total versus Share of Rural Population and Share of Commercial Energy in Primary Energy Total versus Share of Urban Population, 1800-1998. Sources: Nakićenović et al. (1998), CENSUS (2002)
 Note: Commercial Energy is included coal, oil, gas, hydro and nuclear.

A particularly strong historical relationship is found by looking at the “intensity” in the use of traditional biomass in the economy. Figure 6 shows a standard measure of intensity—biomass per unit GDP—as a function of income. With economic development the role of traditional biomass in the economy has declined exponentially. The rate of decline in biomass intensity (-4%/yr) has been more rapid than the decline in primary energy intensity (-1%/yr). Economic development has slowly decoupled from energy inputs, but the decoupling from traditional biomass has been more rapid.

On the basis of observations from the history of biomass use in the United States, we can make the following conclusions:

- Over the last 200 years the share of traditional biomass in primary energy consumption has declined with economic development.

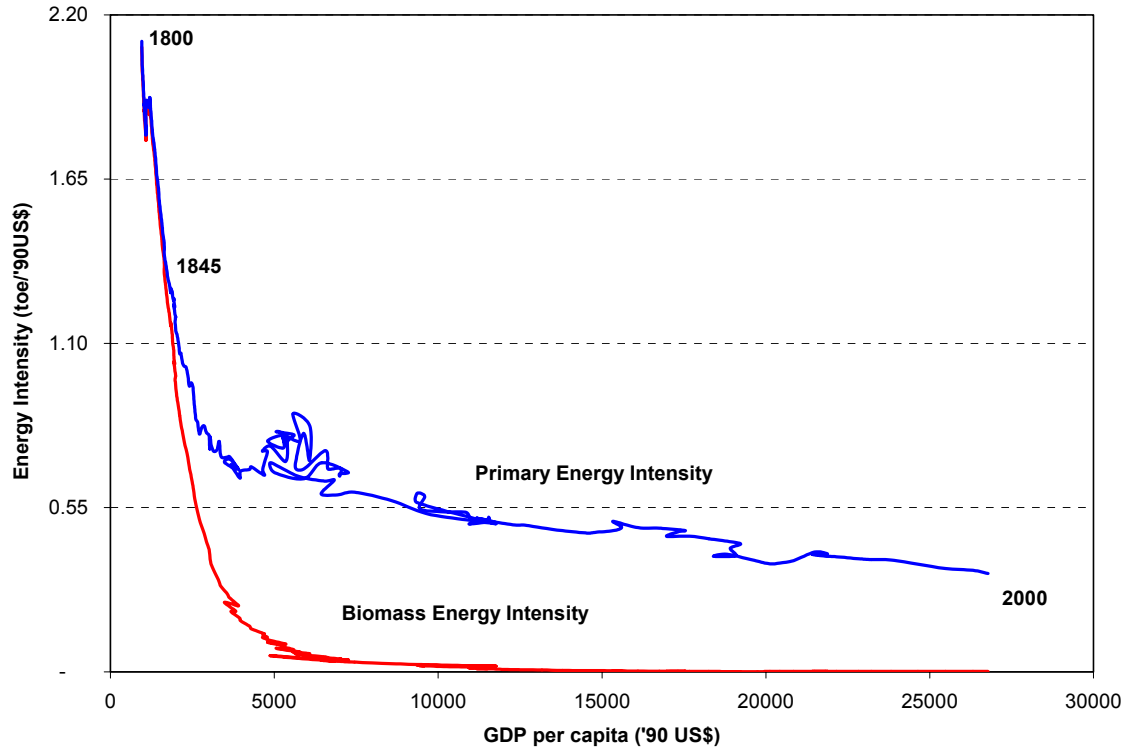


Figure 6. Primary Energy Intensities of GDP and Biomass Intensities of GDP, USA, 1800-2000. Source: Nakićenović et al. (1998), EIA (2002), BEA (2002)

- The greatest decrease of traditional biomass share in primary energy is observed during the period of industrialization—from the 1830s to about 1910. Industrialization was accompanied by an “energy transition” away from traditional biomass and toward modern fuels. Per-capita consumption of biomass peaked in about 1830 and has declined thereafter.
- Despite the constant decline in the share of traditional biomass in primary energy and in per-capita consumption of biomass, in the first decades of industrialization the absolute quantity of traditional biomass consumption actually increased, peaking in 1870.
- One stable relationship that could be useful for long-term projections is the relationship between traditional biomass intensity and income. With economic growth, intensity in the use of biomass declines exponentially.

We now turn to examining patterns in traditional biomass consumption today. First, however, we must examine the data sources that are available and explain which sources are most valid for analysis.

III. Data Sources for Developing Countries

Despite the significance of biomass at the world level, this energy source is often treated as a mere footnote item in most sources of global energy statistics. Traditional biomass energy usually is excluded from analyses of global energy demand trends. This energy source is not regularly monitored in the same way as conventional or commercial energy sources because of the difficulties associated with collecting biomass energy data and the decentralized nature of biomass energy systems. Nevertheless, most large countries gather at least some data on traditional biomass energy, and some international organizations assemble those national data and provide additional estimations. The Appendix to this paper summarizes the main international sources of this data.

Biomass energy is mainly used in the household sector in developing countries, where on average it accounts for about 75 percent of the total final energy use. However, traditional biomass also provides an important fuel source for traditional industries and for services in urban areas as well as in rural zones.

Collecting and preparing biomass energy statistics is a complex process for several reasons: diversity in consumption patterns, variation in heat contents of the different types of biomass, differences in measurement of volume and weight, lack of regular surveys on biomass energy supply and consumption, and differences in definitions.

Not all countries use the same energy units, and national and international data sets often use different conversion factors. In particular, conversion factors vary markedly according to the assumed “heating values” of the fuel. Some countries deliberately lump all biomass fuels under “fuelwood” because the many different biomass fuels account for a small portion of total energy and it is costly to account for each fuel separately. In addition, available data may not coincide in timing, which

Countries	Fuelwood consumption (10e3 cum)			Fuelwood consumption (PJ)		
	CEERD/AIT	FAO	UN	CEERD/AIT	FAO	UN
Bangladesh		30,620	5,900		299	57
Bhutan		1,334	1,270		13	12
Cambodia	8,503	6,484	6,512	82	64	63
India	352,065	269,157	269,182	3,405	2,628	2,603
Laos		4,381	4,392		43	42
Myanmar		19,931	20,040		196	194
Nepal	16,736	19,692	18,000	196	192	174
Sri Lanka		8,809	9,538	148	86	92
Thailand	54,218	36,188	68,639	351	353	664
China	334,242	203,923	204,059	3,233	1,992	1,974
Countries	Share of fuelwood energy in total energy (%)			Share of biomass energy in total energy (%)		
	CEERD/AIT	FAO	UN	CEERD/AIT	FAO	UN
Bangladesh		47	9			53
Bhutan		87	82			80
Cambodia	84	90	89	86		90
India	29	20	20	44		23
Laos		89	88			90
Myanmar		63	62			68
Nepal	68	77	70	91		92
Sri Lanka	65	48	51	67		53
Thailand	19	13	24	26		35
China	10	6	6	23		6

Table 1. 1994 traditional biomass data for various countries and from different sources

Note: CEERD/AIT - Center for Energy-Environment Research and Development (CEERD), a center involved in research and development activities on energy and environmental field since 1986 at Asian Institute of Technology, has established a regional database on energy and environment for Asia and Pacific countries. FAO - Food and Agricultural Organization, provides domestic production, import and export of fuelwood and charcoal. UN – United Nations energy statistics presents fuelwood and charcoal consumption data in different units. Biomass fuel in this statistics refers to fuelwood, charcoal, Bagasse, animal, vegetal and other wastes. See Appendix for details.

prevents precise comparisons. Therefore the data are likely to be different in different databases. Table 1 samples three major data sets to illustrate these differences for a few Asian countries.

The fuelwood data from the FAO and UN databases are comparable in most countries, but this commonality should not be viewed as a measure of accuracy. Both these data sets rely on national data, and the UN databases rely heavily on FAO data. However, these data differ significantly in the case of CEERD/AIT databases. The differences are even larger when looking at all biomass energy (see Appendix for definitions).

What is the "best" estimate for traditional biomass energy use? This is a not easy question to answer. In the analysis presented in this paper we have mainly relied on fuelwood and charcoal data from FAO's database for the following reasons:

- FAO's database covers most countries and often the longest historical data series (since 1960).
- UN energy statistics rely heavily on FAO statistics for most countries, and thus the UN usually does not offer primary data or a more consistent methodology.
- In a very large number of countries, fuelwood is the main readily available source of traditional energy. The share of fuelwood and charcoal in traditional biomass consumption varies, but often is very high (e.g., 86 percent of traditional energy in Asia is fuelwood, according the UN energy statistics yearbook).

IV. Patterns in Traditional Biomass Consumption in Developing Countries

The historical observations, based on the long time series of the US, confirm the expectation that with socio-economic development, households and industries move from low-quality fuels, such as traditional biomass, to more convenient and efficient fuels, such as kerosene, coal, oil, gas and electricity. We now examine that transition and its character in today's developing countries.

Figure 7 shows a cross section of countries in 1996, revealing a strong log-linear relationship between the share of fuelwood in total energy consumption and the rise in income. (Income is compared here in terms of "purchasing power parities (PPP)" so as to offset the tendency for income comparisons based on market exchange rates to under-state the true growth in incomes. That understatement is particularly pronounced at low income levels, such as in the countries shown here.) The data shown here are national averages and do not directly account for distribution of income. Generally, as income increases, fuelwood share in total household energy consumption will decline. However, the picture could change enormously if income distribution is taken into.

Figure 8 shows time series data for a subset of countries, confirming that the contribution of fuelwood to total primary energy consumption tends to decline as income rise. The exact share of fuelwood in the energy system varies considerably across countries, but the basic pattern of declining share with income is strongly evident at low income levels. In countries with higher income levels—illustrated in Figure 8 with Argentina and South Africa—the progression to lower shares for fuelwood is more erratic.

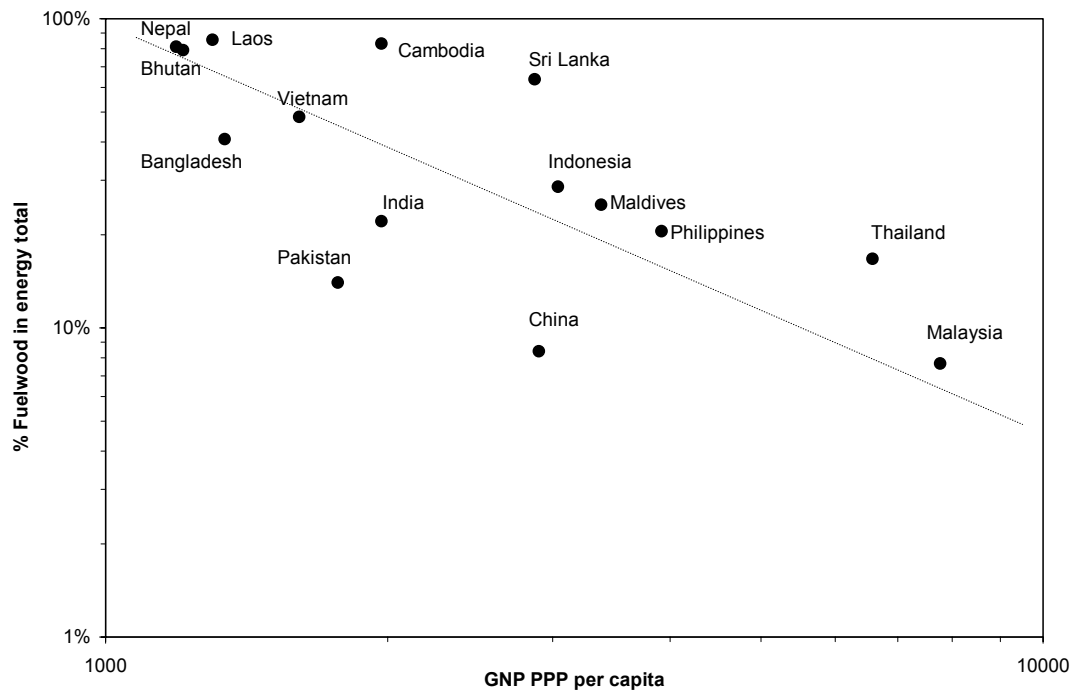


Figure 7. Share of fuelwood versus GNP (PPP) per capita in 1996. Source: UN, WB (2002).

No country that we have examined arrives at a zero share for fuelwood—nor for traditional biomass more generally. Even at high incomes these sources account for some share of energy supply.

The numbers indicate that dependence on fuelwood energy tends to decrease with higher level of economic development. One source of variation in this general pattern derives from measure of “traditional biomass” used for these charts: firewood and charcoal. As shown in table 2, for most countries these are the main sources of traditional biomass. However, the fraction varies substantially, and in some key countries (e.g., China), fuelwood is not the dominant source of biomass.

One factor that affects the role of fuelwood and charcoal in the traditional energy system is availability of fuelwood and its substitutes. India, for example, has a per capita income comparable to Cambodia, but the contribution of fuelwood to total energy consumption in India is less than in Cambodia—other agriculture-based energy sources are more readily available in India, and fuelwood is scarcer. Figure 9 provides a very crude illustration of the relationship between fuel availability and share. In countries where

forests are scant, such as in China, fuelwood accounts for a small share of energy consumption; in highly forested nations, such as Cambodia and Laos, where forests cover about 70% of land area, wood is dominant.

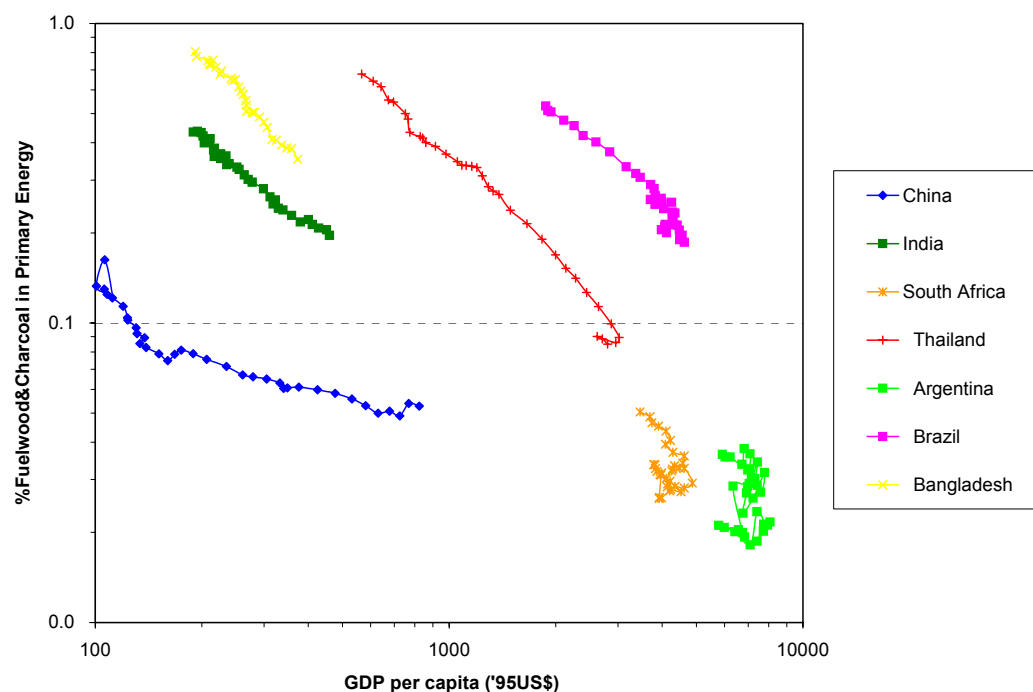


Figure 8. Share of traditional biomass in primary energy consumption versus GDP per capita, 1961-2000. Source: FAO (2002), WB (2002), BP (2002).

	Animal dung	Crop residues	Fuelwood
Bangladesh	13%	61%	25%
Bhutan	0%	0%	100%
Cambodia	0.02%	2%	98%
China	3%	54%	43%
India	14%	23%	63%
Indonesia	0%	6%	94%
Laos	0%	0%	100%
Malaysia	0%	46%	54%
Maldives	0%	0%	100%
Myanmar	0%	1%	99%
Nepal	7%	4%	89%
Pakistan	19%	22%	60%
Philippines	0%	36%	64%
Sri Lanka	0%	2%	98%
Thailand	0%	30%	70%
Vietnam	0%	29%	71%

Table 2. Biomass consumption by different fuels (%).
Source: Regional Wood Energy Development Programme in Asia (RWEDP) 2002.
Note: fuelwood includes charcoal

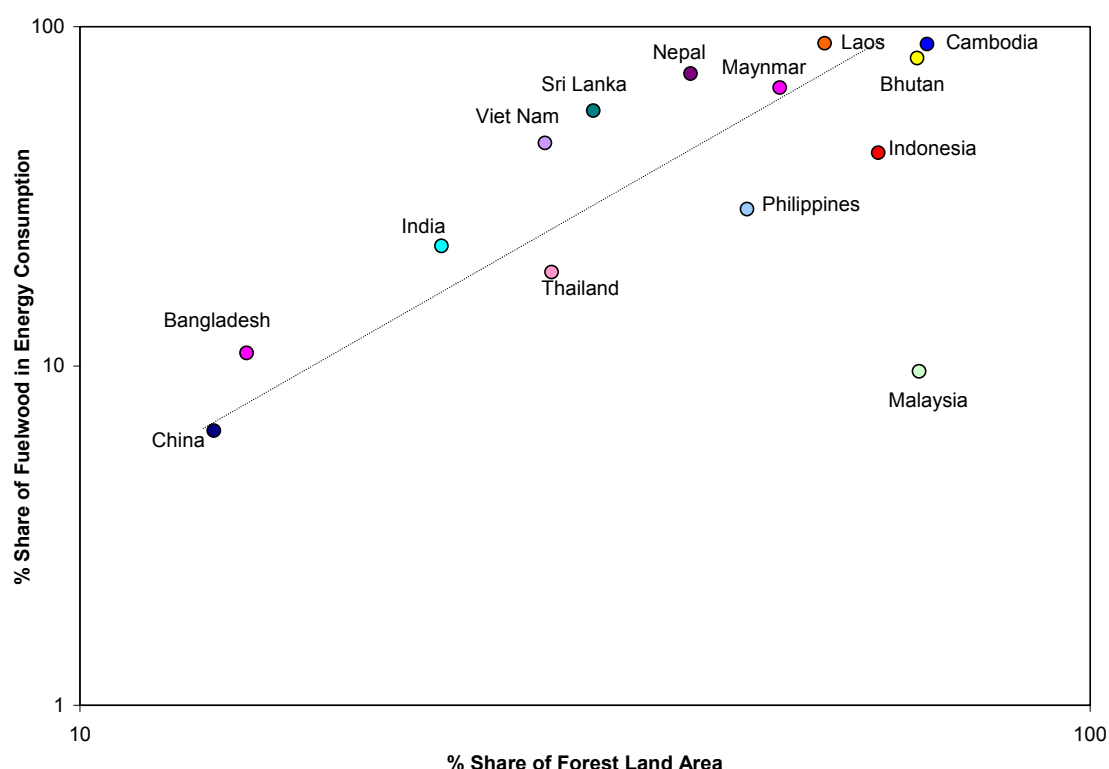


Figure 9. Share of fuelwood versus share of forest area in 1996. Source: UN, FAO (2002)

So far, we have suggested that changes in income and changes in the availability of fuels are major explanations for share of traditional biomass in total energy consumption and the choice of traditional biomass fuel. In seeking a full explanation for these choices, still other factors come into play – such as the country's degree of urbanization and industrialization.

Figure 10 illustrates the relationship between urbanization and traditional biomass consumption, and Figure 11 shows influence of the industrialization level on share of fuelwood. These two additional factors—urbanization and industrialization—are themselves correlated (but not perfectly) with income.

In sum, there appear to be four factors that largely explain the level of traditional energy in an economy and the choice of particular traditional fuels: income, availability of fuels, urbanization and industrialization. In countries with high per capita income, industrialization and urbanization, the share of biomass in energy consumption is smaller. In the countries with low per capita incomes, predominantly rural, and a minor role for industry in the economy, the share of biomass in total energy can reach 80% or more. In

countries with abundant forests close to population centers, firewood plays a large role in the traditional energy system; in other countries alternative agriculture-based fuels are left to a larger share. Even accounting for these factors the model would still be far from complete. Other factors that the literature suggests are important include the availability and price of different conversion equipment (e.g., stoves); climate, geography and land use; culture and traditions (traditional preferred foods and cooking techniques).

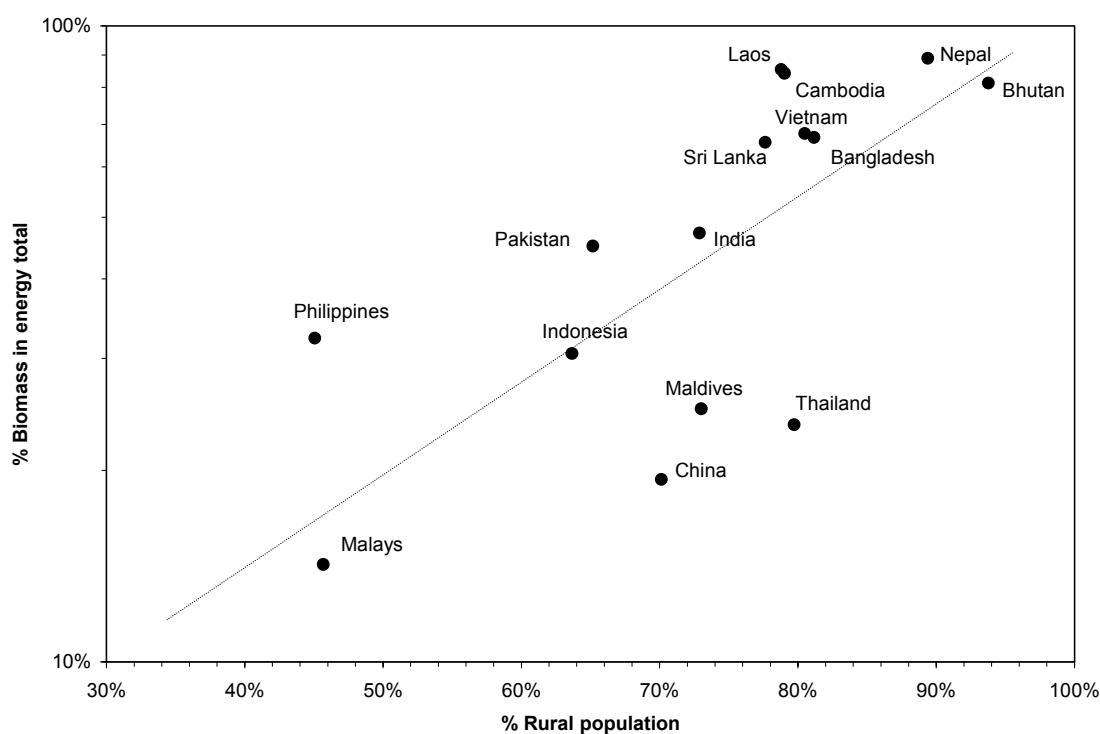


Figure 10. Share of traditional biomass in energy consumption versus share of rural population, for various countries, 1996. Source: RWEDP (2002), WB (2002)

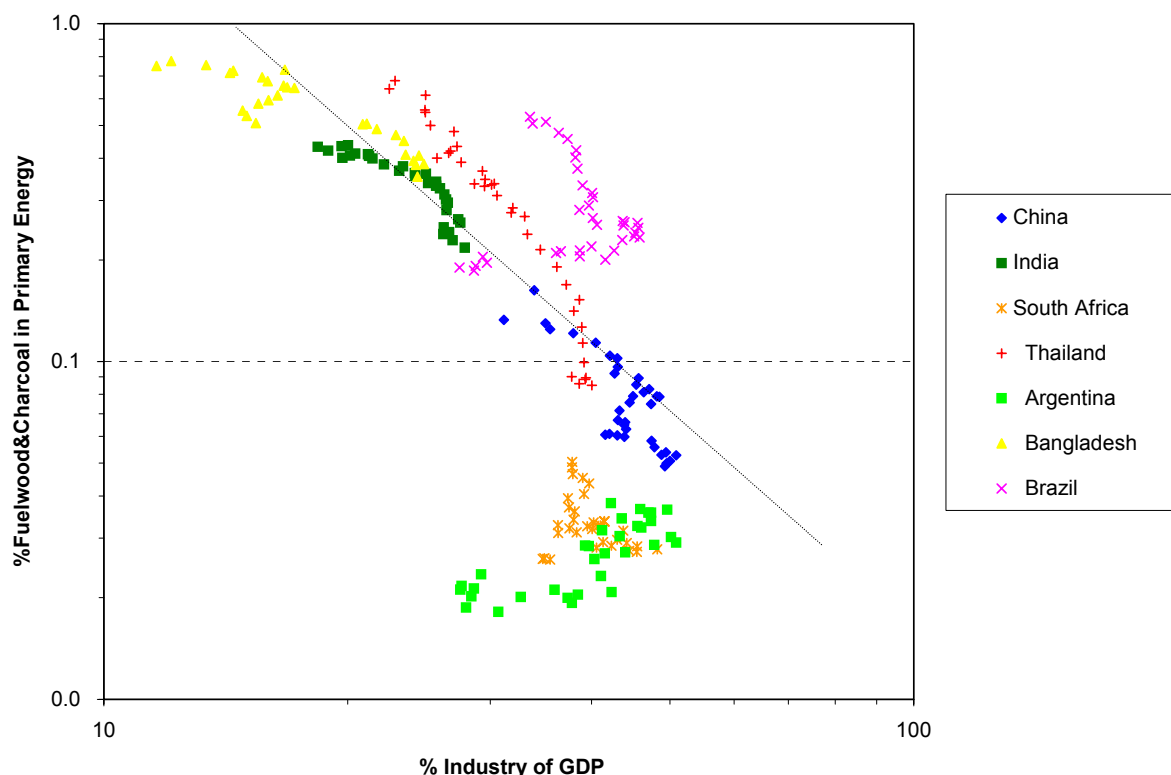


Figure 11. Share of fuelwood and charcoal in primary energy consumption versus share of industry in GDP. Source: FAO (2002), WB (2002)

There has been a tendency to ignore these cultural and contextual factors in macro scale quantitative assessments of the energy system—in part because scholars have not found ways to quantify them easily. However, these factors appear to be very important. In countries with widely varied income levels, urbanization, and fuel availability per-capita consumption of traditional biomass can vary only little. Figure 12, for example, suggests that Asian countries with comparable geography, climate and culture have similar biomass per capita consumption though the levels—even though their levels of economic development are highly varied. Indeed, Figure 13 shows the same countries and reveals a strong relationship between the total population and traditional biomass consumption. This would suggest that attempts to project to the future might find it useful to examine clusters of similar countries rather than to create a general model that explains all conditions.

The analysis of the historical US data and the developing countries that we presented earlier suggests that the driving forces and paths for traditional biomass consumption are similar. The share of biomass energy consumption decreases with

economic development—what we have called the “energy transition.” However, the total amount of traditional energy utilized in the economy varies in more complicated ways. The U.S. data suggest that in the early stages of industrialization that consumption of traditional energy actually rises because this energy is used in industry and additional income allows purchase of higher quantities of energy. The U.S. data suggest that eventually the share and quantity decline, although we have not been able to discern a similar pattern in the macro data presented for these developing countries—either because that pattern is not general or, more likely, the data time series is too brief. The data presented for both the U.S. and the developing countries suggest that total consumption of traditional energy depends on population; the data for the Asian countries presented in Figures 12 & 13 suggest that, at least for a limited period of time, total population size may be the dominant factor because cultural and social determinants of fuel choice change only slowly.

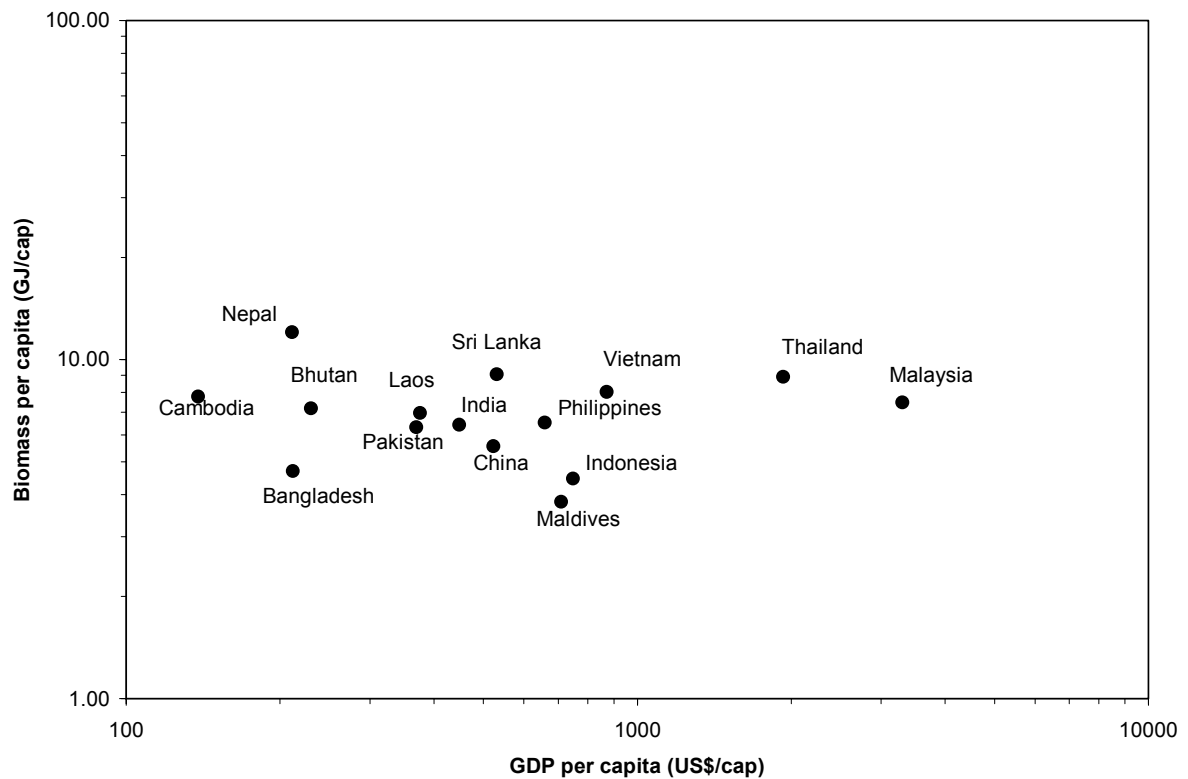


Figure 12. Biomass per capita versus GDP per capita in 1996. Source: RWEDP (2002), WB (2002)

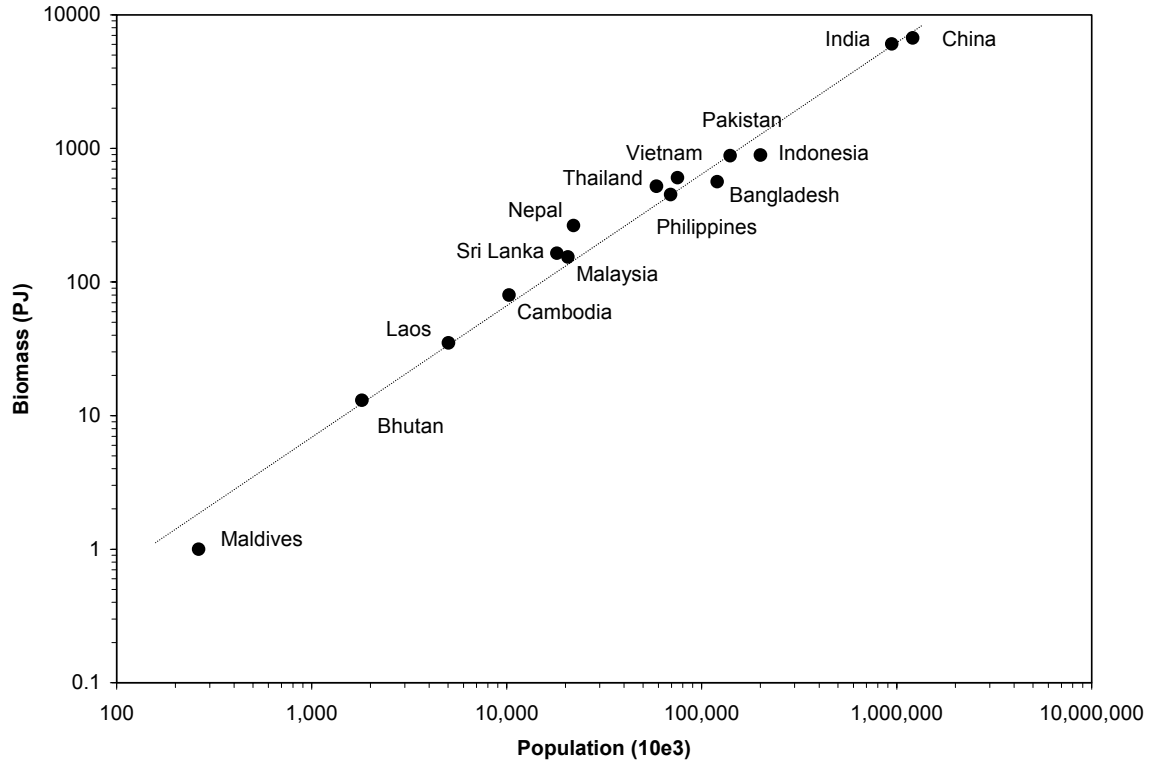


Figure 13. Biomass consumption versus population for various countries in 1996. Data source: FAO (2002), UN

V. Techniques for Projections in Developing Countries

So far we have identified a set of driving forces that appear to explain the share and level of traditional biomass in the energy system as well as the total level of biomass consumption. The treatment of these forces has been far from complete, and the purpose of this essay has been to provide an overview of the main forces. Now we turn to the task of making some incomplete and speculative projections for the future—as illustration of the types of models that might be developed and tested and the uses to which they could be applied.

In this paper, we address only what appears to be the simplest task: projections of biomass intensity. As we have seen in the historical data for the U.S. that intensity has declined steadily with economic growth. Figure 14 shows biomass intensity that was measured as Fuelwood & Charcoal and GDP ratio for selected developing countries in Africa, Asia and Latin America. Indeed, as expected, there was a steady and rapid improvement of biomass intensity for all countries. Even if fuelwood consumption per

person remains constant—as suggested earlier, at least for a subset of Asian countries—a rise in income will yield a decline in biomass intensity. The rate of change varies considerably, however. In the newly industrializing economies of Thailand and China the average biomass intensities improvement rates 8 percent annually—about double the long-term historical rate when the U.S. underwent industrialization. However, in some countries the rate of change is low—such as the Central African Republic and South Africa.

How does biomass intensity vary with growth in income? In order to answer this question for every country presented at the Figure 14 we estimated parameters of a power function:

$$Y=a X^b,$$

where **Y** is the biomass intensity of GDP; **b** is the progress ratio; **X** is the GDP per capita; and **a** is a scale coefficient that reflects the biomass and GDP ratio of the first observation. Results from the regression are shown in Table 3.

The regression analysis confirms strong relationship between a dependent and independent variable for most of the countries. R-square (the proportion of variation in the dependent variable explained by the regression model) is close to 1 for almost all observed countries except for the Central African Republic (see Table 3).

The maximum rate of decline in biomass intensity is observed in Thailand (-8.3% annually) and China (-7.8% annually), the countries that also demonstrated the highest growth in GDP per capita during the period. The minimum decline in biomass intensity was observed in Angola (+1.2 %), where GDP per capita also decreased during the period. Countries that started at a relatively high level of biomass intensity generally demonstrated the most rapid decline in intensity.

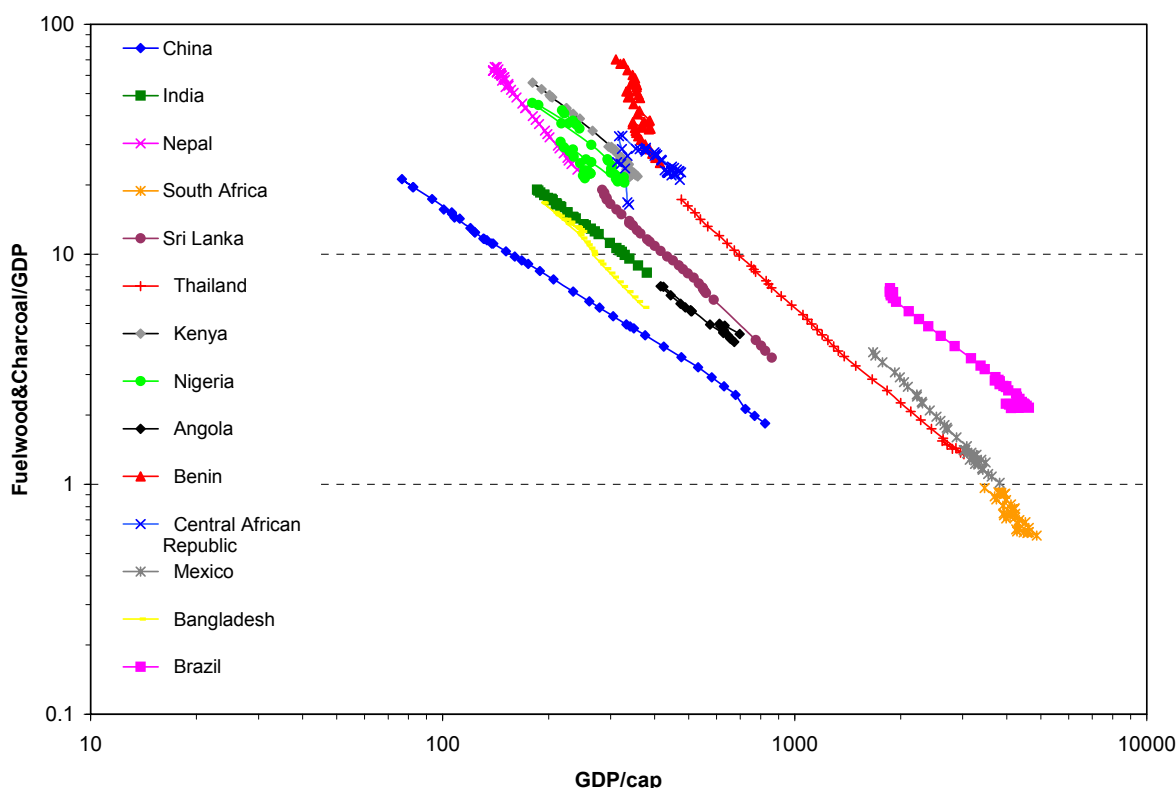


Figure 14. Biomass intensity of GDP versus GDP per capita in 1961-2000. Source: FAO (2002), WB (2002)

Using this simple model we can calculate biomass intensities for 2020 and estimate the future fuelwood and charcoal consumption for India and China. That task requires exogenous assumptions for growth in GDP, which we derive from OECD projections (OECD, 1997) as well as exogenous assumptions about population growth, for which we use the United Nations medium case (UN, 2002).

According to our estimations, if GDP in China grows about 5% annually and population rises 0.6% annually in 2000-2020, total fuelwood and charcoal consumption in 2020 will be 17 percent higher than in 2000 or would increase annually at a rate of 0.8%. Fuelwood and charcoal consumption in India will increase by 14 percent with annual average rates 0.7 %, based on the assumption that GDP growth will be 4.1% and population growth 1% annually in 2000-2020.

	Annual Average Growth rates (observed)		Nonlinear Regression Analysis Results		
	GDP per cap	Biomass Intensity	R ²	A	B
Angola	-1.6%	1.2%	0.97	3895	-1.05
Bangladesh	1.8%	-3.0%	0.97	84287	-1.61
Benin	0.8%	-3.4%	0.55	18774556	-2.20
Brazil	3.2%	-4.0%	0.99	105945	-1.28
Central African Republic	-1.1%	-0.9%	0.13	225	-0.37
China	8.3%	-7.8%	0.99	1624	-1.00
India	3.2%	-3.5%	0.99	6651	-1.12
Kenya	2.1%	-3.2%	0.99	83408	-1.40
Mexico	2.9%	-4.4%	0.99	559649	-1.60
Nepal	1.9%	-3.4%	0.99	747180	-1.89
Nigeria	0.5%	-2.3%	0.65	105902	-1.49
South Africa	1.2%	5.5%	0.70	16886	-1.20
Sri Lanka	3.9%	-5.6%	0.95	24305	-1.28
Thailand	6.3%	-8.3%	0.99	128503	-1.45

Table 3. Average Annual Growth Rates of GDP per capita and Biomass Intensity and Results of Nonlinear Regression Analysis.

Note: R² - R-square (the proportion of variation in the dependent variable explained by the regression model)

A - a scale coefficient that reflects the biomass and GDP ratio of the first observation

B - the progress ratio

On a per-capita basis, fuelwood and charcoal consumption in China in 2020 at approximately the same as in 2000. In India, per capita fuelwood and charcoal will decrease: in 2020 will be 6 percent lower than in 2000 and will reach about 2.9 GJ per person. To put these projections into perspective, the development of China's traditional energy system corresponds with the period around 1830 in the United States, and India corresponds with the period between 1830 and 1870. Obviously there are many differences, not least that these projections are on the basis of fuelwood and charcoal data; a full projection for traditional biomass would need to examine other fuels.

We are aware of only two earlier efforts to quantify the macro patterns and make projections for the use of traditional biomass in developing countries. Lefevre (1997) presents 3 different scenarios for future fuelwood consumption in Asian countries: (a)

business-as-usual (BAU), (b) "green" energy, and (c) massive fossil fuel promotion. In that model, the future growth in fuelwood consumption is determined by its past and present rate of growth, which are derived from regression analysis. Elasticities that measure the responsiveness of fuelwood consumption to economic and population growth are the major drivers in this model, although the published results do not actually report all of the estimations. That model is similar to the simple regression analysis presented here.

A study by IEA offers biomass projections for Africa, Latin America, China, East Asia and South Asia (Lambert D'Apote, 1998). In order to isolate the effect of growing population, the author of that study chose per capita biomass consumption as the dependent variable. The study hypothesized that there would be many variables that could influence the level of per capita biomass consumption, notably: GDP per capita, level of conventional energy use, price of alternative fuels, share of urban population, availability of supply of biomass fuels and price of final biomass fuels. However, in developing their projections they did not deploy all of these variables. Using available historical series for a number of Latin American and Asian countries, and one or two countries in Africa, several equations were estimated to test the relationships between several independent variables and the level of biomass per capita; they also sought relationships between those independent variables and the share of biomass in total energy consumption. They concluded that the most important independent variable was per capita income, while the effect of fuel prices was found to be small. They found that urbanization was too highly correlated with income to have much explanatory power of its own. Thus in making their projections for biomass per capita they appear to have relied on GDP per capita as the driving force. They found that income elasticities were negative (but smaller than 1)—that is, per capita use of biomass decreased as per capita income increases. In those instances where they found that price elasticities for the competing fuel were positive (when significantly different from zero), which implies that per capita biomass use will grow if the price of the competing fuel increases (for example if subsidies are removed).

VI. Final Comments and Suggestions for Further Research

Currently about 2.4 billion people of the developing countries rely on traditional biomass and over half of all people relying on biomass for cooking and heating live in India and China. Nevertheless the proportion of the population depending on biomass is higher in sub-Saharan Africa than in Asia: extreme poverty and the lack of access to other fuels mean that 80 percent of the overall African population relies primarily on biomass to meet its residential needs.³

³ In Kenya, Tanzania, Mozambique and Zambia, almost all rural households use wood for cooking, and over 90% of urban households use charcoal. In Indonesia, almost all rural households use wood for cooking. In East Asia, the heaviest biomass use occurs in the Philippines, Thailand, Myanmar and Vietnam.

There appear to have been very few studies that examine macro trends in the use of traditional fuels. The analysis here, although incomplete, suggests two tracks for further research. First, it would be useful to perform long time series analyses for countries other than the United States in an effort to uncover robust patterns in the changing use of traditional fuels. The most robust pattern is the decline in biomass intensity with economic growth, but other patterns also seem to emerge from the data. France, Germany, Japan and the U.K. are all candidate countries—each with long time series data and long experience with the process of industrialization. However, this will be a complex and time consuming task as the normal sources of comparable economic data (e.g., Mitchell) do not have much information on traditional fuels.

The second track would involve development of more sophisticated regression models that could be used for projections. So far, the poor quality of the data and the complexity of relationships between variables seems to have precluded the development of all but the simplest regression models, such as the one presented here. Moreover, the macro data suggest that there are cultural and geographical factors that affect the deployment of traditional energy sources in the economy, and those factors could be extremely difficult to include in a model. Perhaps if additional work at the macro level is coupled with micro-level analysis explored in other papers at this workshop that the relevant hypotheses for testing in regression models will be clearer and advance could be made on this front.

Works Cited

- BEA (Bureau of Economic Analysis). 2002. National Accounts Data and supporting data tables, posted on <http://www.bea.doc.gov/bea/dn1.htm>.
- BP (British Petroleum). 2002. *Statistical Review of World Energy 2002* and supporting data tables, posted on <http://www.bp.com/centres/energy2002/>.
- CENSUS (U.S. Census Bureau). 2002. Posted on <http://www.census.gov/population/censusdata/table-4.pdf>
- EIA (Energy Information Administration). 2002. *Annual Energy Review* and supporting data tables, posted on <http://tonto.eia.doe.gov/aer/index2000.htm>.
- FAO (Food and Agricultural Organization of the United Nations). Different years. *Forest Products Yearbook*. Rome: FAO.
- FAO. 2002. FAOSTAT and supporting data tables, posted on <http://www.fao.org/forestry/include/frames/english.asp?section=http://apps.fao.org/page/collections?subset=forestry>.
- Grübler, Arnulf, Nebojša Nakićenović and David G. Victor. 1999. Dynamics of Energy Technologies and Global Change. *Energy Policy* 27: 247-280.
- IEA (International Energy Agency). 1998. *Biomass Energy: Data, Analysis and Trends*. Paris: IEA Publications.
- IEA. 2002. *World Energy Outlook 2002*. Energy and Poverty (Chapter 13), posted on <http://www.worldenergyoutlook.org/weo/pubs/weo2002/energypoverty.pdf>.
- Lambert D'Apote, S. 1998. IEA Biomass Energy Analysis and Projections. In *Biomass Energy: Data, Analysis and Trends*. Paris: IEA Publications. URL: <http://www.iea.org/pubs/proc/files/bioend/index.htm>
- Lefevre, T. et al. 1997. *The Role of Wood Energy in Asia, Center for Energy-Environment Research & Development*. Bangkok, Thailand: Asian Institute of Technology. November 1997, posted on <http://www.fao.org/docrep/w7519e/w7519e00.htm>
- Mitchell, B.R. 1998. *International Historical Statistics: Vol. I (The Americas 1750-1993), Vol. II (Europe 1750-1993) and Vol. III (Africa, Asia & Oceania 1750-1993)*. New York: Stockton Press.

Nakićenović, Nebojša et al., eds. 1998. *Global Energy Perspectives*. Cambridge: Cambridge University Press; Laxenburg, Austria: IIASA (International Institute for Applied Systems Analysis).

OECD (Organization for Economic Cooperation and Development). 1997. *The World in 2020: Towards a New Global Age*. Paris: OECD.

RWEDP (Regional Wood Energy Development Programme in Asia). 2002. Database. URL: http://www.rwedp.org/d_database.html.

UN (United Nations). 2001. *World Population Prospects: The 2000 Revision and World Urbanization Prospects*. United Nations, Population Division of the Department of Economic and Social Affairs of the United Nations Secretariat, posted on <http://esa.un.org/unpp>

UN. Various years. *Energy Statistics Yearbook*. New York: UN.

WB (World Bank). 2002. *World Development Indicators*, CD-ROM.

Appendix

Available traditional biomass energy statistics

There are several institutions that monitoring traditional biomass energy data and provide the datasets for various developing countries (see Table 1 and text below for details):

- International Energy Agency (IEA)
 - United Nations (UN)
 - Food and Agricultural Organization (FAO)
 - World Energy Council (WEC)
 - Latin American Energy Organization (OLADE)
 - Asia-Pacific Energy Research Center (APEREC)
 - ASEAN-EC Energy Management Training and Research Center
 - Southern African Development Community (SADC)
 - CEERD/AIT energy and environmental database.
-
- IEA collects energy supply and demand data for all OECD countries and more than 100 non-OECD countries. These data are collected for all fuels and are then converted, where necessary, into a common energy unit to produce energy balances on country and regional basis. Data are collected through official bodies in OECD Member countries and several non-OECD countries, through industry contacts as well as in co-operation with regional and international organizations such as EUROSTAT, UN-ECE in Geneva, the UN in New York and OLADE. The data collection methodology is somewhat different for OECD and Non-OECD Countries.

IEA collects data on non-OECD countries covering all fuels following the same classification as for OECD countries. However, as the IEA has no mandate to collect these data, various methods are applied. For UN-ECE Members, data are collected annually from national administrations on the same questionnaire as for OECD countries. For other non-OECD countries, the data are collected from various sources, such as national publications or statistics, regional organizations and specific studies or surveys. Where otherwise unavailable, the IEA uses data from the UN. Although the same classification for OECD and non-OECD countries is used, for non-OECD countries, there is a more detailed breakdown of energy commodities.

Most of the data for Africa based on data from South African Development Community, African Development Bank, United Nations, Food and Agriculture Organization. Only South Africa has a reasonable time series. Middle East the data are from the United Nation and the FAO. A few countries of Asia have reliable time series, such as Nepal, Philippines, Sri Lanka and Thailand. Most of the other countries have had

several studies or surveys of biomass energy but rarely are there consistent time series. For China, India, Bangladesh, Myanmar, Pakistan and Vietnam the data are based on numerous sources and the Secretariat has estimated the data based on a per capita average from the various surveys and studies. For the other countries, data has been estimated based on data from UN and FAO.

IEA statistics do not distinguish between new, modern, traditional or commercial types of fuels. Rather fuels are separated and treated based on their inherent qualities. For example, wood used in a simple stove and wood used in a highly efficient industrial boiler are both reported under the product wood with consumption being reported in the residential and industrial sectors respectively. An exception to this rule is the treatment of Municipal Solid Wastes, which often includes fuels such as biomass and vegetal wastes. It is treated as a separate fuel due to the difficulty of accurately measuring the various contents. Biomass products serve a number of needs, including fuel, feed and fodder. For commodities, which serve both energy and non-energy uses, that part of production which serves energy needs, inferred from consumption, is included in the balance.

For each of these four fuel groups, data are collected from production through to final consumption. Most data are collected and reported in physical units, e.g. tones, cubm, baskets, headloads, etc. Data, which are received in physical units are converted into energy units for storage in the database.

The overall IEA data quality is still poor as many data are often from secondary sources and inconsistent, which makes comparisons between countries difficult. Moreover, the historical data of many countries derive from surveys, which were often irregular and irreconcilable and the IEA has estimated data where it was incomplete (but this is true for all other data sources).

- UN energy statistics presents fuelwood and charcoal consumption data in different units. Fuelwood consumption is presented in cubic meter, while charcoal is presented in tones. However, domestic production and export of charcoal are already included into the domestic fuelwood production. Imported charcoal is converted into equivalent fuelwood and presented in cubic meter. Hence, total fuelwood consumption is given as:

$$\text{Fuelwood total (cubic meter)} = \text{Fuelwood (cubic meter)} + \text{Imported charcoal (in tonne)} / (\text{eff} * d)$$

where,

eff = Factor converting fuelwood to charcoal or charcoal kiln efficiency; the value taken is 0.2254;

d = Factor converting volume to weight of fuelwood or density of fuelwood on dry basis, the value taken is 0.725.

Energy Statistics Yearbook is an annual publication of the United Nations presents time series (for the past 4 years) data on production, trade and consumption of various types of energy commodities for the countries all over the world. Since this statistics presents data for past four years and the data of the earlier issues are always revised in the new issues, this study uses various issues of this statistics.

Statistics includes both conventional and biomass energy commodities. The conventional commodities included in the statistics are coal (hard coal, lignite, coke, peat, hard coal briquettes and lignite and peat briquettes), petroleum (crude petroleum, LPG, aviation gasoline, motor gasoline, kerosene, jet fuels, gas-diesel oils, residual fuel oil), gas (natural gas, other gas) and electricity (hydro, thermal, nuclear). The biomass fuels included in the statistics are fuelwood, charcoal and Bagasse. Data for each type of fuel and aggregate data for the total mix of conventional fuels are provided for individual countries as well as summarized into regional and world tables.

The data in this statistics are compiled primarily from annual questionnaires distributed by the United Nations Statistical Division and supplemented by official national statistical publications. Where the official data are not available or are inconsistent, estimates are made by the Statistical Division based on governmental, professional or conventional materials.

Fuelwood in this statistics is defined as "all wood in the rough used for fuel purpose. Fuelwood production data include the portion used for charcoal production, using a factor of 6 to convert from a weight basis to the volumetric equivalent (metric tons or cubic meters) of charcoal". Similarly, charcoal is defined as "solid residue consisting mainly of carbon obtained by the destructive distillation of wood in the absence of air". Biomass fuel in this statistics refer to fuelwood, charcoal, Bagasse, animal, vegetal and other wastes.

- FAO Forests Products Yearbook (FAO, different years) provides domestic production, import and export of fuelwood and charcoal in volumetric unit (thousand cubic meters). FAO is calculated wood energy supply data from the following relationships:

$$\text{Wood energy supply} = \text{Domestic production} + \text{imports} - \text{Exports}$$

With an assumption that there is no transportation and distribution losses of wood energy, wood energy supply equals to wood energy consumption.

The statistics presents data for fuelwood and charcoal separately as well as jointly. This study considers data for fuelwood from "fuelwood + charcoal" category of the statistics.

Data of FAO statistics are collected by means of questionnaires send to concerned departments of all countries in the world. However, in the absence of official replies of the questionnaires, data are either estimated by FAO or obtained from other sources. The data for all countries under this study are estimated data (not the real data) and are subjected to change in the next issues of FAO Forest Product Yearbook if suggested officially by the governments or new information were available from any other sources. The estimates of fuelwood production data are based on the per capita fuelwood production and population growth rate (this methodology seems to be not very accurate).

The definitions of forest products follow the classification and definitions of forest products, FAO, Rome, 1982. Data are highly aggregated (wood energy consumption by sector is not available). No information is given on total energy consumption; hence, the importance of wood energy can not be interpreted in terms of its contribution to total energy requirement.

- FAOSTAT Forestry database provides the estimates of the annual production of numerous forest products by country and historical data are available from 1961. These estimates are provided through an annual survey that FAO conducts in partnership with the International Tropical Timber Organization, the UN Economic Commission for Europe and EUROSTAT (the Council for European Statistics). The collection of the database has been made possible by the cooperation of governments, which have supplied most of the information in the form of replies to annual questionnaires. Where countries have not reported statistics to FAO or have reported only partially, the information has been taken from national yearbooks, from reports or from unofficial publications. Where data are not accessible, FAO repeats historical figures until new information is found. The commodities included are fuelwood, coniferous and non-coniferous and the roundwood equivalent of charcoal (using a factor of 6.0 to convert from weight (Mt) to solid volume units (cum)).
- CEERD/AIT Energy-Environment Database. Center for Energy-Environment Research and Development (CEERD), a center involved in research and development activities on energy and environmental field since 1986 at Asian Institute of Technology, has established a regional database on energy and environment for Asia and pacific countries. The database currently has data on energy and environment for 22 countries. In this database, a separate group has been created for wood energy data. Although attempts have been made to gather wood energy data and information from different countries, only a few countries (Nepal, Sri Lanka and Thailand) have a complete time series on wood energy data, whereas for the rest of the countries have only partial data (data for a few years).

The database presents data tables in aggregated and detailed forms. Aggregated tables present main biomass energy commodities such as fuelwood, charcoal, agricultural residues, dung, biogas, municipal wastes and wood derived liquid fuel (e.g., black liquor, ethanol, methanol) in columns and time series data in rows. Data tables are designed for each type of activities or flow like resources/reserves, production, trade (imports/exports), total supply, transformation and final consumption. Consumption data are also presented by types of economic sectors (e.g., household sector, commercial and service sector, industrial sector and others). Detailed tables are aimed to provide in-depth information of a particular type of fuel or activity. For example, fuel wood is divided into different components such as primary fuelwood, wood residues, sawdust, furthermore production of fuelwood is disaggregated according to its sources such as fuelwood from natural forests, fuelwood from on-farm forests etc.

AIT database provides the data for both: fuel wood and charcoal. Data are presented in mass unit (thousand tons). They are converted into volume unit as follows:

Fuelwood total (cubic meter) = Fuelwood (tons)/d + imported charcoal (in tons) /(eff * d), where "eff" and "d" have the same values as in the UN statistics.

The main characteristic of AIT database is that no data based on estimation. Whatever data are available are taken from the published or prepared (but not published) statistics of national level institutions. Most of the existing data are taken from regular publications and provides time series, however, some data are taken from special studies, reports and correspond to the particular point of time.

Table A1. Institutions and Comparative Terminology Currently Used

Organization	Biomass Energy Data	Definition
IEA	Combustible Renewables and Wastes	<p>A. Solid Biomass and Animal Products</p> <p>Wood</p> <p>Vegetal material and waste</p> <p>Black liquor</p> <p>Animal products (for publications, combined with other solid biomass)</p> <p>Other solid biomass and animal products</p> <p>B Gases from Biomass and Wastes</p> <p>Landfill gas</p> <p>Sludge and sewage gas</p> <p>Other gases from biomass and wastes</p> <p>C Liquids from Biomass and Wastes</p> <p>Alcohols (ethanol, methanol, etc)</p> <p>Bio-additives (eg from oleaginous plants)</p> <p>Other distilled liquids from biomass & wastes</p> <p>D Industrial waste</p> <p>E Municipal waste</p> <p>F Charcoal (a secondary product)</p>
United Nations (UN)	Traditional Fuels	<p>Fuelwood: All wood in the rough used for fuel purposes. Production data include the portion used for charcoal production, using a factor of 6 to convert from a weight basis to the volumetric equivalent (metric tonnes to cubic metres) of charcoal</p> <p>Bagasse: The cellulosic residue left after sugar is extracted from sugar cane. It is often used as a fuel within the sugar milling industry.</p> <p>Charcoal: Solid residue consisting mainly of carbon obtained by the destructive distillation of wood in the absence of air.</p> <p>Animal Wastes: Dung and other non-dried excreta of cattle, horses, pigs, poultry, and the like and, in principle, humans, used as a fuel.</p> <p>Vegetal Wastes: Mainly crop residues (cereal straw from maize, wheat, paddy rice, etc.) and food processing wastes (rice hulls, coconut husks, ground-nut shells, etc.) used for fuel. Bagasse is excluded.</p> <p>Alcohol: Ethanol and methanol used as a fuel.</p>
Food and Agricultural Organisation (FAO)	Wood products and on the energy use of fuelwood and charcoal	<p>Fuelwood: Wood in the rough (from trunks and branches of trees) to be used as fuel for purposes such as cooking, heating or power production.</p> <p>Charcoal: Wood carbonised by partial combustion or application of heat from an external source and used as a fuel or for other purposes.</p>
World Energy Council (WEC) Latin American Energy Organisation (OLADE)	Fuelwood (including charcoal) Biomass energy	<p>the same as FAO</p> <p>Fuelwood: The energy which is obtained directly from forest resources. It includes tree trunks and branches and waste from sawmilling activities, all of which fall under the definition of "other plant and animal fuels" used for energy purposes.</p> <p>Sugarcane Products: The sugarcane products which are used for energy purposes, among these are bagasse, cane liquor (juice) and molasses.</p> <p>Other Primary Sources:</p> <p>Vegetable or Plant Fuels: The energy resources obtained from agro-industrial and forestry residues (except sugarcane bagasse) for energy purposes.</p> <p>Animal Fuels: The residue of agricultural/livestock activities and urban wastes used directly as fuel in a dry form or converted into biogas.</p> <p>Recovered Energy: Substances with an energy content produced in industrial plants as a by-product of the production process, for example, furnace gas, black liquor, etc.</p> <p>Charcoal: The fuel obtained from the destructive distillation of the wood from charcoal plants, in the absence of oxygen, with a net calorific value of around 6500 kcal/kg.</p> <p>Alcohol: This includes both ethanol (ethyl alcohol) and methanol (methyl alcohol) used as fuels.</p> <p>Process Gases: This category includes the gaseous fuels obtained as by-products of activities in refineries, coke plants and furnaces, as well as the gas obtained from biogasifiers. (Includes Refinery Gas, Furnace Gas, Coke Gas, Condensed Gas and Biogas.)</p>
ASEAN-EC Energy Management Training and Research Centre (AEEMTRC) Southern African Development Community (SADC)	Wood, Other Biomass and Charcoal Woodfuel, Biomass and Charcoal	<p>No data definitions are provided.</p> <p>Woodfuel: all fuels derived from wood, including wood or firewood itself, plus charcoal and woodwastes. The column "wood in the balances includes both firewood and woodwastes.</p> <p>Biomass: includes all vegetal and animal fuels except woodfuel, i.e. crop residues, bagasse, dung, etc.</p>
Center for Energy-Environment Research and Development (CEERD)	Biomass Energy	<p>all terrestrial and aquatic vegetation, its residues (fuelwood, twigs, dead leaves, shell), cultivated crops and their residues (cereal straw, seed-husks, Bagasse), livestock products and their residues (e.g., dung).</p> <p>Wood fuel: all types of lignocellulosic material derived directly and indirectly from plants, trees, shrubs, and herbaceous plant grown in forest as well as non-forest lands and used for fuel purpose. Fuelwood, charcoal and wood derived fuels (e.g., black liquor, methanol, ethanol).</p> <p>Charcoal: it is a solid residue derived from carbonization, distillation, pyrolysis and torrefaction of wood (from trunks and branches of trees) and wood by-products using pit, brick and metal kilns. It includes also charcoal briquettes made from wood-based charcoal.</p>