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# WOODFUEL PRODUCTIVITY OF AGROFORESTRY SYSTEMS IN ASIA

## A review of current knowledge

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*Cover Page Photo* : *Woodfuel collection on farmland in northern Luzon, Philippines*



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## TABLE OF CONTENTS

**Page**

**INTRODUCTION** .......... 1

**1. BACKGROUND** .......... 2

1.1 Agroforestry and other land uses in Asia .......... 2

1.1.1 Definition of agroforestry .......... 2
1.1.2 Land use data .......... 2
1.1.3 Size of landholdings .......... 4

1.2 Present woodfuel situation .......... 5

1.2.1 Consumption/demand and supply - present and future .......... 5
1.2.2 Local and between-country variations .......... 8
1.2.3 The role of woodfuels in total energy supply .......... 8

1.3 Sources of fuelwood .......... 9

1.3.1 Forest and non-forest sources .......... 9
1.3.2 Woodfuel from agroforestry systems - examples from Bangladesh and West Java .......... 9

**2. WOODFUEL SUPPLY FROM AGROFORESTRY SYSTEMS** .......... 10

2.1 Agroforestry classification used in this paper .......... 10

2.2 Reported wood productivity of agroforestry systems .......... 11

2.2.1 Productivity of individual systems .......... 11
2.2.2 Wood productivity by agroforestry system class and ecozone .......... 16
2.2.3 Land needs for woodfuel supply .......... 16
2.2.4 Individual tree productivity in different agroforestry system classes .......... 18

2.3 Factors influencing the actual woodfuel supply .......... 19

2.3.1 Environmental conditions .......... 19
2.3.2 Species choice .......... 20
2.3.3 Production priorities .......... 20
2.3.4 Management .......... 20
2.3.5 Socio-economic factors .......... 21
2.3.6 Infrastructure and distribution .......... 21
2.3.7 Policies and legislation .......... 21

2.4 Optimizing woodfuel production .......... 22

**3. EVALUATING AND PLANNING WOODFUEL SUPPLY FROM AGROFORESTRY SYSTEMS** .......... 24

3.1 Evaluating woodfuel energy needs .......... 24

3.2 Evaluating woodfuel resources .......... 25

3.2.1 Estimating biomass .......... 25
3.2.2 Estimating productivity .......... 26

3.3 Local level planning .......... 26

3.3.1 System and species selection .......... 26

3.4 Large scale planning .......... 27

3.4.1 Data handling and planning tools .......... 27

**4. CONCLUSIONS** .......... 29

**5. REFERENCES** .......... 31

**APPENDICES**

**A:** Trees listed as woodfuel suppliers in ICRAF Multipurpose Tree and Shrub Database .......... 37

**B:** Energy units and conversion factors .......... 40

# INTRODUCTION

The aim of this paper is to review the current scattered knowledge concerning the woodfuel production capacities of traditional as well as new agroforestry systems. Agroforestry is extensively advocated as a sustainable and productive form of landuse and hence quantitative knowledge of its productive capabilities is essential to any process of landuse evaluation and planning.

Woodfuels, here defined to encompass fuelwood and charcoal, are important products of agroforestry systems that will continue to be a major source of energy in developing countries, especially in rural areas. In contrast to earlier views of forests as the most important woodfuel supplier, a major part of woodfuels has been found to originate from trees on non-forest land, which in many cases will mean from some kind of agroforestry system. Agroforestry systems are therefore beyond any doubt a very important woodfuel supplier, and this may become even more pronounced as the use of agroforestry systems are further promoted.

It is hoped that the present paper, can provide some initial indications and guidelines as to what output of woodfuels is to be expected in a given situation. This may serve as a starting point from where, in combination with data on woodfuel demand, the further evaluation and/or planning of landuse, e.g. the area and/or system necessary to supply sufficient amounts of woodfuels can be carried out. This should, subsequently, be combined with local information on infrastructure and socio-economic data to provide a realistic basis for land use planning.

The focus of this paper is primarily local farmers with average or below average resources, who form the majority of the rural agricultural population. However, a large part of the data and discussions are of a general nature and will also be relevant for larger scale enterprises that are capable of higher inputs.

Although the paper has concentrated on the countries which are part of the Regional Wood Energy Development Programme or Asia Pacific Agroforestry Network of FAO, conditions are in many respects similar in several other neighboring countries in the area like Cambodia, Southern China, Malaysia and will be relevant in part to these also.

At first the very limited data on agroforestry land use in the region is reviewed together with data on other types of land use. A brief overview of the current woodfuel situation in Asia, as far as this is known, is presented, including woodfuel demands, supply sources and the importance of wood energy in total energy consumption. The data on various sources of woodfuels and their reliability is also discussed.

Following this background information, a review of the current available data on woodfuel production in agroforestry systems is given. In an attempt to provide some order, the reported data have been arranged according to a rough climatic and structural classification. This is followed by an account of the factors that may influence the actual supply and to which the researchers and planners must pay due attention. This again leads to a number of general approaches whereby woodfuel production can be optimized. The possible use, implications and limitations of these kinds of productivity data for land use and energy planning at various scales is discussed. This includes a brief review of the various measurement options and their limitations for estimating wood volumes and productivity of agroforestry trees.

# 1. BACKGROUND

## 1.1 Agroforestry and other land use in Asia

### 1.1.1 Definition of agroforestry

Several definitions of agroforestry have been suggested but, in short, agroforestry is generally perceived as the deliberate cultivation of several productive components, of which at least one is a woody perennial, on the same piece of land, combined either spatially or sequentially.

This definition can be further specified:

a. There should be an interaction between the components;
b. A sequential combination must be, at least partly, within the same growing season;
c. The growing cycle is longer than one year;
d. Other components can be animals, scrubs or annual crops;
e. There is at least two outputs and it is usually expected that total areal output of these is higher than that of a monoculture of either component.

### 1.1.2 Land use data

One crucial obstacle in estimating the woodfuel supply from agroforestry systems on a national level, is that the actual amount of land occupied by the multitude of agroforestry systems is insufficiently known. This is partly due to the term "agroforestry" still being new and not yet uniformly perceived by statisticS agencies. Agroforestry systems may be included in several of the categories usually applied in land use statistics such as: forest land, wood land, degraded land, agricultural lands, urban areas (homegardens) and "other land use" (e.g. road side plantings). But even for well established categories such as "forest land" statistics should generally be treated with some caution. Hopefully, the increased use of satellite imagery will improve this situation. Some scattered information on some systems or areas in the region does exist though, and is presented in Table 1. For West Java, the most densely populated province in Indonesia, some more detailed information exists. This shows that homegardens occupy 8-9% of total land area, which is less than the average of 20% for the whole island of Java. In addition, mixed tree gardens cover 20% and *Tegalan*, which is mostly practiced as an annual-perennial rotation system, covers 9.5%. Plantations cover 7% of total land and may also include agroforestry practices, although the extent is not known. Altogether this means that somewhere between 35 and 45% of the land is cultivated with some kind of agroforestry system. Obviously this is an important source of woodfuels as will be shown later. Agroforestry practices are also very extensive in the Philippines and Sri Lanka where they cover about 30% and 19% of the land, respectively. For Bangladesh, available information only reports about 2.3% of land covered by homegardens. It is not known however, if other systems are practiced. The figure of 12% given for Vietnam is very uncertain and is probably more a target than a fact. On the other hand, traditional agroforestry practices are widespread in upland areas of Vietnam although their exact land coverage is not known. For several other countries agroforestry practices are known to be common but unfortunately no specific data on their occurrence is available. This includes India, Thailand and Nepal.

**Table 1: Agroforestry and forest land use in the Asian region as a percentage of total land.**

| Country | Forest 1)* | Forest 2)* | Type of Agroforestry system: Homegardens | Tree gardens | Shifting cultivation | Inter-planted plantations | Annual crops with trees | AF as a percentage of of total land |
|---|---|---|---|---|---|---|---|---|
| Bangladesh | 14 | 6 | 2.3 | | + | (+) | + | 2.3 |
| Bhutan | 56 | 60 | | | | | | |
| India | 22 | 17 | + | | + | + | + | n.a. |
| Indonesia | 63 | 60 | | | 6 | | | |
| Java | | | 20 | + | | + | + | |
| W. Java | 19.4 | | 8-9 | 20 | | (7) | 9.5 | 35-45 |
| Myanmar | 49 | 44 | | | + | + | + | n.a. |
| Nepal | 18 | 37 | (+) | (+) | | (+) | + | n.a. |
| Pakistan | 5 | 2 | | | | | (+) | |
| Philippines | 35 | 26 | + | | 6.0 | 13.8 | 13.6** | 14 (-33#) |
| Sri Lanka | 32 | 27 | 9.3 | | | 9.9 | | 19 |
| Thailand | 28 | 25 | (+) | (+) | 1.6 | + | + | n.a. |
| Vietnam | 30 | 26 | + | | | 0.8 | (12) | (12) |

Note: * Figures may include some agroforestry land use.
** Assuming that an average of 40% of mixed extensive farmland is actually cultivated, as estimated by Soussan (1991).
# Including shifting cultivation and cultivated mixed extensive farmland.
+ Existence reported but no data on area. (+) = Limited descriptions

Sources: Abedin and Quodus (1990), Mellink et al. (1991), REDEP (1988), Tejwani and Lai (1992)
1) Data for 1990, FAO (1992). 2) FAO (1993)

The data on forest cover is FAO data which is based on official information from the respective countries. Unfortunately, these figures may often only represent land which, legally, is within the jurisdiction of the forestry departments, but are not necessarily covered with forest any more. As an example, a recent study in the Philippines by Soussan (1991) based on satellite images showed actual forest cover to be about 24% in comparison with the official figure of 35% (FAO,1992).

*Figure 1: Trees on farmland terraces, India.*

### 1.1.3 Size of landholdings

The average agricultural area available per capita of agricultural population in Asian countries is presented in Table 2, but it should be stressed that these are average figures. Bangladesh for instance, has a quite large proportion of the agricultural population classified as landless. Although much of this landless population apparently still possesses homegardens (Abedin et al. 1990), instead of being classified as agricultural land, these production systems are often included in "urban areas". Furthermore, farmers in many countries cultivate land which is legally forest land, hence the actual agriculturally cultivated area in a particular location may differ considerably from official statistics. Actual landholdings may also include land which is not classified as agricultural land in statistics, but is still planted or can be planted, with trees, like roadsides, canal banks etc. The average size of landholdings will be further discussed in connection with the wood productivity data presented in Chapter 2.

**Table 2: Agricultural land per capita for agricultural population in Asian countries in 1990 (ha).**

| Country | Agricultural land /capita | Agricultural land/ household * |
|---|---|---|
| Bangladesh | 0.12 | 0.68 |
| Bhutan | 0.10 | 0.65 |
| India | 0.32 | 1.76 |
| Indonesia | 0.27 | 1.32 |
| Lao PDR | 0.22 | 1.34 |
| Myanmar | 0.52 | 2.70 |
| Nepal | 0.15 | 0.87 |
| Pakistan | 0.32 | 2.11 |
| Philippines | 0.27 | 1.51 |
| Sri Lanka | 0.21 | 1.09 |
| Thailand | 0.66 | 3.43 |
| Viet Nam | 0.16 | 0.85 |
| Average | 0.28 | 1.54 |

* Based on average household sizes in Table 3. Source: FAO (1992)

## 1.2 Present woodfuel situation

Although economic development is progressing rapidly in many Asian countries and the use of fossil fuels is correspondingly gaining in importance, it is realized that woodfuels (wood and charcoal), particularly in rural areas, will continue to play a major role in national energy supply for many years ahead (Soussan, 1991; Koopmans, 1993). Bearing in mind the finiteness of fossil fuels one may also reason the sensibleness or perhaps eventual necessity, of using a potentially renewable energy source such as wood.

### 1.2.1 Consumption/demand and supply - present and future

In order to evaluate or plan for the adequate supply of woodfuels one obviously needs to have rather precise information on the demand and supply situation which is relevant to the area in question. This has always been a major problem since most woodfuels are collected, traded and used locally and hence only enter the market economy to a limited extent. Even within the same country major differences between local situations may exist and in any large scale study the dangers of generalization must be carefully weighed against the efforts needed to obtain sufficiently locally relevant data on which to base extrapolations (various tools and approaches for larger scale studies, like LEAP and GIS, will be discussed in Chapter 3).

A considerable amount of data has been published in the past describing the woodfuel demand and supply in different countries and areas of the region and much planning and speculation has been based on these data. Unfortunately, the vast majority of these figures were at best either qualified guesses or incomplete and hence should have been treated as such; but this was not always the case. These inaccurate and incomplete data on demand, supply and sources were the main basis for the creation of the so-called "gap theory" and the declaration of a fuelwood crisis a decade ago. Major errors may thus arise if imprecise and/or incomplete primary data are extrapolated to regional and national levels. Most UN data on woodfuel demand/consumption are derived by multiplying estimated per capita consumptions with population figures. Recently, several more in-depth studies conducted in Bangladesh, Myanmar, Sri Lanka and Viet Nam have arrived at figures that differ markedly from the UN data. These studies show national wood energy consumption to be up to twice the previously reported figures (Koopmans,1993). Apart from inaccuracies, this was ascribed to the fact that UN data did not include wood used by small scale industries like brick making, tobacco-curing, potteries etc. Although it has been established that fuelwood gathering in general is not a major cause of forest destruction, and that the bulk of fuelwood is supplied from various types of non-forest land (Koopmans, 1993; REDEP, 1988), a significant amount of fuelwood is in some cases obtained by illegal collection from state forests. Precise data on these amounts are not likely to be obtained through conventional interviews with villagers and data from such areas should be interpreted with caution.

*Figure 2: Fuelwood is primarily used for domestic cooking in Nepal.*

In Table 3 currently available data on woodfuel demand/consumption is presented, but should be interpreted bearing in mind the reservations already mentioned. In particular, a distinction should be made between the terms "demand" and "consumption" which often seem to be used inter-changeably although they are not necessarily identical, e.g. if there is not enough fuelwood supply demand will be higher than consumption. It has not been possible to clearly distinguish them in all literature sources, but in Bangladesh and India and possibly Pakistan the figures should probably be read as consumption since actual demand is more likely to be higher if compared to demand country data, especially if the widespread use of cow dung as fuel is substituted with wood.

## Table 3: Estimated annual woodfuel demand/consumption in Asian countries

(kg dry weight)

| Country | Annual household demand/consumption in kg | | Consumption/demand per capita in kg (year) | Country consumption in Mill. t (year) | Average household size |
|---|---|---|---|---|---|
| Bangladesh | urban<br>rural | 906<br>222 | 159<br>39<br>(1981) | 5.5<br>(1981) | 5.7 |
| Bhutan | | 7052 | 1085<br>(1990) | 0.8<br>(1989) | 6.5 |
| India | | 836 | 152<br>(1990) | 162.1<br>(1990) | 5.5 |
| Indonesia | urban<br>rural/urban | 402<br>2288-2470 | 82<br>504 | 93.2 # | 4.9 |
| Laos | | 3538 | 580 | 2.4<br>(1989) | 6.1 |
| Myanmar | | 3276 | 630 | 27.1<br>(1990) | 5.2 |
| Nepal | urban<br>rural | 1438<br>2958 | 248<br>510<br>(1980/81) | 11.7<br>(1988/89) | 5.8 |
| Pakistan | | 1947 | 295 | 33.0<br>(1992) | 6.6 |
| Philippines | capital<br>urban<br>rural | 425<br>1557<br>2262 | 16+60 [15]*<br>138+140 [35]<br>408+102 [26]<br>(1989) | 29.1<br>(1989) | 5.6 |
| Sri Lanka | | 2647 | 509<br>(1990) | 12.6<br>(1990) | 5.2 |
| Thailand | urban<br>rural | 629<br>2865 | 29+92 [23]*<br>135+416 [104]<br>(1983) | 23.9<br>(1988) | 5.2 |
| Viet Nam | | 2650 | 500 | 33.0<br>(1988) | 5.3 |
| Average urban<br>rural | | 986<br>2817 | 178<br>481 | - | 5.6 |

Notes: Household demand based on average household size
# Author's estimate based on population of 185 million and 504 kg/cap consumption.
700 kg/m$^3$ used in case of conversion.
( ) If known, year of survey indicated in parentheses
* Consumption was split into 1) fuelwood and 2) charcoal expressed in fuelwood equivalents. Actual charcoal amount indicated in parentheses.

Sources: Koopmans, (1993); WRI, (1992); Soussan et al, (1991); Directorate General of Electric Power and New Energy (1985). REDEP, (1988), Ministry of Agriculture, Bhutan (1991).

### 1.2.2 Local and between-country variations

As can be seen from Table 3 there are major differences in woodfuel consumption between urban and rural populations. This is, among other reaons, related to the increased availability of other energy sources in urban areas in combination with the higher modern "appeal" of these. Since the share of urban populations is expected to grow in most of the region, demand patterns are bound to change. But although the share of the agricultural population is decreasing, the actual population will still continue to grow, making the absolute demand for woodfuels grow as well. In Bangladesh the relation between rural and urban woodfuel consumption is atypical, because rural farmers sell their fuelwood in order to gain cash income and use lower grade fuels like agricultural residues and, in particular, cow dung for themselves. The use of cow dung is also widespread in some areas of India, Pakistan and Burma and is obviously very unfortunate since the dung was much better used as an organic fertilizer and soil improver in agricultural fields.

Predictably, the fuelwood demand is higher in mountainous areas of Nepal, Pakistan and Bhutan in particular, where room heating is necessary. The figures in Table 1 are averages covering large local variation. For instance in lowland Nepal, average per capita consumption is 383 kg annually, whereas in mountainous areas it is 636 kg (Koopmans, 1993). Demographic factors, like migration from uplands to lowlands, from rural to urban etc, are hence important to consider when forecasting fuelwood needs. The estimated annual per capita consumption in Bhutan of 1200 kg (Ministry of Agriculture, Bhutan, 1991) seems very high and may be caused by inaccuracies in the estimation procedure.

Forecasts for future woodfuel needs are generally based on population estimates combined with per capita consumption data and thus influenced by the same errors as previously described plus the additional inaccuracies in population predictions. To give specific figures for future wood energy needs may thus seem futile, but it would be safe to assume a demand at least equal to the present level or more likely higher, especially in rural areas.

### 1.2.3 The role of woodfuels in total energy supply

According to data from the World Resources Institute the share of "traditional" energy sources in the above countries, including fuelwood, charcoal and agricultural residues, ranged from 25 to 95% of total energy supply in 1989 (WRI, 1992). However, data from other sources indicate the consumption of traditional energy sources to be even higher than this in several countries including Bangladesh, India, Myanmar, Pakistan, Sri Lanka and Vietnam. These statistical differences, for which there is no obvious explanation, are as high as a factor two or three (Koopmans, 1993). This indicates the importance of woodfuels which in many cases may be underestimated in prevailing statistics and hence subsequently in energy policies and planning. This situation is emphasized by the fact that woodfuel issues are generally under the authority of the forestry departments and not the energy departments and that very little cooperation exists between these agencies.Although fossil fuels generally dominate in urban areas, also in the household sector, data on woodfuel use in urban West Java (Indonesia) surprisingly suggest consumption is increasing. This is probably related to the withdrawal of Liquified Petroleum Gas(LPG) subsidies (ESMAP, 1990) as well as to the fact that there was a surplus of woodfuel in West Java as a whole at the time of the study (REDEP, 1988).

## 1.3 Sources of fuelwood

### 1.3.1 Forest and non-forest sources

By forst land is generally meant land which legally is within the jurisdiction of the forest department. As is the case with data on woodfuel consumption the sources of fuelwood are not known in any great detail. Results from a number of local studies, however, have served to indicate that forests in general are not the major supplier of woodfuels and that in most Asian countries the majority of woodfuels indeed are collected from various types of non-forest land, including homegardens, agricultural fields, roadsides etc. This is contrary to the general view held only a decade ago, and still in some forest departments, which regarded fuelwood gathering as a major cause of forest destruction. In Vietnam, Pakistan, Sri Lanka, Philippines and Java (Indonesia) 75-85% of woodfuel consumption is estimated to originate outside forest lands. In Thailand, the share is about 50%, whereas in Nepal and Bhutan the majority is still thought to be supplied from forests. Data from India are somewhat unclear because purchased wood has no indication of source, hence 47-74% of fuelwood consumption could originate from non-forest land. The specific amounts in question for the various countries has been discussed in more detail by Koopmans (1993).

Some reservations about the reliability of the village studies which form the basis of these data, especially regarding the reporting of woodfuel sources, must be stressed though. Most of these studies are carried out in the form of interviews with farmers, often with the interviewer being accompanied by a forestry official acting as interpreter and/or facilitator. Obviously the farmers are not likely to speak freely about the amount of wood collected "illegally" from state forests in such a situation and hence this woodfuel source would tend to be underestimated in many surveys.

### 1.3.2. Woodfuel from agroforestry systems - examples from Bangladesh and West Java

In Bangladesh, it has been estimated that, although wood as such does not play a major role in the total energy supply, homegardens however supply 90% of all the fuelwood consumed. Most of this fuelwood is sold by the farmers to urban consumers in order to gain a cash income. The farmers themselves use lower grade fuels, such as agricultural residues and cow dung.

In West Java, Indonesia, a major study was carried out that served to emphasize the importance of agroforestry systems for fuelwood supply. It was found that such woodfuels accounted for more than half the total energy consumed (Koopmans, 1993). In West Java 83 % of all biomass supply is wood originating from village land and an additional 10% of biomass in the form of rice husks and straw is supplied. The remainder is supplied from plantations and forests. And 17% is supplied from home gardens, 47% from mixed tree gardens, 13% from rainfed fields of annuals and tree crops *(tegalan)*, 2% from trees in ricefields and 4% from other areas, like roadsides etc. (REDEP, 1988). Since the distribution of land use differs considerable between districts in West Java, the northern part being dominated by ricefields, the situation is not equally favorable everywhere. Several northern districts thus face woodfuel deficits, whereas most central districts are in balance and southern districts have a surplus. The average surplus hence requires a considerable flow of woodfuels between districts to ensure an actual positive supply all over the province of West Java.

## 2. WOODFUEL SUPPLY FROM AGROFORESTRY SYSTEMS

### 2.1 Agroforestry classification used in this paper

Agroforestry systems may be classified according to a number of different criteria depending on the objectives of categorization. The prevailing system used has been suggested by Nair (1985), and is based on four sets of criteria: System structure, system function, agro-ecological zone and socioeconomic level. These four classes are of course not totally independent. For the sake of simplicity or due to lack of information, the classification used for this paper does not use all these criteria. One system function common for all the systems included here is that they all produce woodfuels, although it is not the major output in all cases. First, the systems have been categorized according to the nature and arrangement of their elements. This includes the following structural compositions:

Agrisilviculture(AS): Composed of agricultural (annual) crops and woody perennials (trees, shrubs and vines)

Silvopastoral(SP): Combinations of pasture and/or animals and trees. In this paper the practice of shrimp farming in mangrove forests (the falling leaves being the "pasture" for the shrimps), termed silvofishery, has been included in this category, although it is normally placed under "other systems".

Agrisilvopastoral(ASP): Agricultural crops, pasture and/or animals and trees.

*Figure 3: Agrosilvopasture near Nakhon Sawan, western Thailand.*

For the purpose of this paper the systems have been further divided into two rough climatic zones, namely humid tropical and subhumid tropical. Humid tropical is here defined as receiving more than 1500 mm of rain annually (MacDicken & Vergara, 1990) and subhumid as areas receiving less than this and having a pronounced seasonal distribution of rainfall. Since only some sources provided data on soil conditions it was not possible to use this parameter for differentiation. For a detailed account of agroforestry classification, which is outside the scope of this paper, the reader is recommended to consult Nair (1985, or 1993) or MacDicken and Vergara (1990).

## 2.2 Reported wood productivity of agroforestry systems

Considering the number of statistics on agricultural products, precise data on fuelwood production are surprisingly scarce, especially data from traditional agroforestry systems. As already mentioned, this is mainly caused by the fact that woodfuels are more often collected than traded, and if traded, then only on a small local level.

### 2.2.1 Productivity of individual systems

In Table 4 the wood productivity reported from a number of agroforestry systems is presented. The majority of data are from various types of experimental plots and should hence be viewed more as potential rather than general average productivity figures in a farming situation. In some of the systems listed in the table, the sources do not clearly state if the wood produced is intended for fuelwood use, but owing to the relatively small size of most of the trees used, the short rotation length and the management practices applied, its potential is in most cases mainly for fuel or pulp. For a few systems though, only the wood lopped or pruned for woodfuels is reported, whereas the total wood production, including poles and timber may be markedly higher. As far as possible both fuelwood and total wood production is presented in order to give a more reasonable basis for comparison of systems.

Before interpreting the data in Tables 4 to 8, it should be stressed that most of these systems are not cultivated with the sole purpose of providing wood, but are supplying fodder, grains, tubers, vegetables, various animal products etc. In many systems it is therefore likely that if more emphasis was put on the woodfuel output, a higher woodfuel productivity could be achieved. Similarly, where the farmer's preference is greater for fodder or other products and hence his management practices are different, woodfuel productivity could be lower than indicated here.

Even within the groupings already described the systems reported still represent a very wide range of situations, for instance regarding tree density: this ranges from alley cropping systems of 50,000 trees per hectare to scattered trees on pasture land. For some systems it may thus be more relevant to look at the production per tree than per hectare.

It is unfortunate that productivity data from several countries like Nepal, Pakistan and Bhutan are not available, especially from their mountainous regions, since such data are likely to differ significantly from lowland area data. To draw any conclusions regarding these areas may thus be questionable on the basis of the following data. As a rule of thumb productivity figures should be expected to be lower than average in high mountain areas due to the shortened growing season, although higher rainfall may counterbalance this to some extent.

**Table 4: Reported annual fuelwood supply of various agroforestry systems** (other product outputs not shown)

| Country | Type of AF-System | | | | | Continuous Supply | | Minimum area to supply 1 household (ha) | Ref |
|---|---|---|---|---|---|---|---|---|---|
| | Class | Rain/Soil | Tree | Tree density no/ha | Crops | t/ha | kg/tree | | |
| HUMID | | | | | | | | | |
| Indonesia | Hum-AS | n.d. | Calliandra calothyrsus | n.d. | n.d. | 22.8-42.3 | | 0.06-0.11 | 2 |
| Indonesia | Hum-AS | n.d. | Several spp. (Tegalan) | n.d. | annual | 8.4 | | 0.28 | 25 |
| Indonesia | Hum-AS | n.d. | Several spp. (Tegalan) | n.d. | annual | 12.6 | | 0.19 | 10 |
| Indonesia | Hum-AS | 1500-2500mm | Acacia mearnsii | n.d. | annual | 7.8-19.4 | | 0.16-0.40 | 3 |
| Indonesia W. Java | Hum-AS | | Mixed tree garden (Kebun campuran) | n.d. | fruit | 15.2 | | 0.16 | 25 |
| Indonesia | Hum-AS | n.d. (West Java) | Mixed tree garden (Kebun campuran) | n.d. | fruit | 18.9 | | 0.13 | 10 |
| Costa Rica | Hum-AS | n.d. | Cordia alliodora | n.d. | cacao | 8.3* | | 0.33 | 13 |
| Costa Rica | Hum-AS | 2637 mm, Alluvial deposits, moderat fertile | Erythrina poeppigiana (3 pruning regimes) | 280 | coffee | 3.5<br>7.9<br>15.2 | 12.5<br>28.2<br>54.3 | 0.8<br>0.35<br>0.18 | 26 |
| Nigeria | Hum-AS | 2200-4320 mm | Gmelina arborea | 1510 | yam, corn, cassava | 19.2 | 12.7 | 0.15 | 1 |
| Indonesia | Hum-SP | Soil pH 6, low sulphur | Calliandra calothyrsus | 40 000 | pasture | 22.1 | 0.55 | 0.11 | 8 |
| Indonesia | Hum-SP | as above | Sesbania grandiflora | 30 000 | pasture | 7.1 | 0.23 | 0.35 | 8 |
| Indonesia | Hum-SP | as above | Leucaena leucocephala | 40 000 | pasture | 29.6 | 0.74 | 0.08 | 8 |
| Indonesia | Hum-SP | as above | Gliricidia sepium | 40 000 | pasture | 15.3 | 0.38 | 0.16 | 8 |
| Asia | Hum-SP | Mangrove | Avicennia/Rhizophora | n.d. | aguafauna | 13.5-58.5 | | 0.05-0.21 | 23 |
| Vietnam | Hum-SP | Mangrove Monsoon, saline soils | Rhizophora/Avicennia/ Bruguiera | n.d. | shrimp | 5.4-9 | | 0.29-0.49 | 29 |

| Country | Type of AF-System | | | | | Continuous Supply | | Minimum area to supply 1 household (ha) | Ref |
|---|---|---|---|---|---|---|---|---|---|
| | Class | Rain/Soil | Tree | Tree density no/ha | Crops | t/ha | kg/tree | | |
| Vietnam | Hum-ASP | Temporarily flooded acid sulphate soils | Melaleuca leucadendron | 20 000 | rice, fish shrimp, | 0.8 fuel*<br>10.2 tot* | 0.04*<br>0.51* | 3.51<br>0.26 | 29 |
| Indonesia W. Java | Hum-ASP | Humid tropical | homegarden | n.d. | fruit, tubers, vegetables animals | 13.1 | | 0.18 | 25 |
| Indonesia | Hum-ASP | n.d. (West Java) | homegarden | n.d. | as above | 15.4 | | 0.15 | 10 |
| SUBHUMID | | | | | | | | | |
| Thailand | Shum-AS | 1000-1500 mm, acrisols | Eucalyptus sp. | 625 | n.d. | 2.1 | 3.36 | 1.36 | 4 |
| Thailand | Shum-AS | (1000-1500 mm)# | Eucalyptus camaldulensis | 625 | cassava | 2.64 | 4.2 | 1.08 | 28 |
| Thailand | Shum-AS | (1000-1500 mm)# | Eucalyptus camaldulensis | 625 | mung bean | 4.90 | 7.8 | 0.58 | 28 |
| Thailand | Shum-AS | (1000-1500 mm)# | Leucaena leucocephala | 625 | cassava | 7.15 | 11.4 | 0.40 | 28 |
| Thailand | Shum-AS | (1000-1500 mm)# | Leucaena leucocephala | 625 | mung bean | 9.79 | 15.7 | 0.29 | 28 |
| Thailand | Shum-AS | (1000-1500 mm)# | Acacia auriculiformis | 625 | cassava | 8.73 | 14.0 | 0.32 | 28 |
| Thailand | Shum-AS | (1000-1500 mm)# | Acacia auriculiformis | 625 | mung bean | 14.35 | 23.0 | 0.20 | 28 |
| India | Shum-AS | 1000-1500 mm | Leucaena leucocephala giant variety | n.d. | papaya, lemon, turmeric, okra | 4.91 | | 0.17<br>(0.57)a | 12 |
| India | Shum-AS | 1000-1500 mm | Leucaena leucocephala | 10667 | maize | 5.09 | 0.47 | 0.16<br>(0.55)a | 12 |
| India | Shum-AS | 1000-1500 mm | Leucaena leucocephala | 10667 | black gum | 6.06 | 0.57 | 0.14<br>(0.46)a | 12 |
| India | Shum-AS | 1000-1500 mm | Leucaena leucocephala | 10667 | clust bean | 5.07 | 0.47 | 0.16<br>(0.56)a | 12 |
| India | Shum-AS | 1660 mm Sub tropical | Morus alba | 100 | rice/wheat | 1.78 | 18.0 | 0.47<br>(1.58)a | 18 |
| India | Shum-AS | 1660 mm Sub tropical, seasonal | Grewia optiva | 100 | rice/wheat | 1.40 | 14.0 | 0.60 | 18 |

| Country | Type of AF-System | | | | | Continuous Supply | | Minimum area to supply 1 household (ha) | Ref |
|---|---|---|---|---|---|---|---|---|---|
| | Class | Rain/Soil | Tree | Tree density no/ha | Crops | t/ha | kg/tree | | |
| | | | | | | | | (2.01)a | |
| India | Shum-AS | 1660 mm Sub tropical, seasonal | Eucalyptus hybrid | 100 | rice/wheat | 2.6 | 26.0 | 0.32<br>(1.08)a | 18 |
| India | Shum-AS | Seasonal | Leucaena latisiliqua | n.d. | fruits | 4.10 | | 0.20<br>(0.69)a | 5 |
| India | Shum-AS | Seasonal | Leucaena sp | 625 | sorghum | 6.70 | 10.72 | 0.12<br>(0.42)a | 20 |
| Bangladesh | Shum-AS | Seasonal | Artocarpus heterophyllus | 125 | annuals | 3.13 | 25.0 | 0.29<br>(0.90)a | 21 |
| Indonesia | Shum-AS | 1500mm, seasonal | Several spp. (Tegalan) | n.d. | annuals | 1.33 fuel<br>2.03 tot | | 1.79<br>1.17 | 19 |
| Indonesia | Shum-AS | Seasonal | Calliandra calothyrsus<br>(Agathis dammara timber) | 1667<br>833 | maize, fruit | 4.41 fuel | 2.65 | 0.54 | 11 |
| Indonesia | Shum-AS | Seasonal | Eucalyptus sp. | 1667 | maize | 8.82 | 5.29 | 0.28 | 11 |
| Indonesia | Shum-AS | Seasonal | Acacia decurrens | 5000 | maize | 13.86 | 2.77 | 0.18 | 11 |
| Nigeria | Shum-AS | 1250 mm Ferric Luvisol | Gliricidia sepium | 5000 | maize | 7.25 t | 1.05 kg* | 0.38 | 29 |
| Nigeria | Shum-AS | as above | Flemingia congesta | 5000 | maize | 3.4 t | 0.49 kg* | 0.83 | 29 |
| Nigeria | Shum-AS | as above | Cassia siamea | 5000 | maize | 14.35 t | 2.03 kg* | 0.20 | 29 |
| Nigeria | Shum-AS | 1280mm Oxic Paleustalfs | Leucaena leucocephala | 20 000 | corn,cowpe | 27.5 t | 1.26 kg* | 0.08 | 6 |
| Nigeria | Shum-AS | as above | Gliricidia sepium | 20 000 | corn,cowpe | 10.15 t | 0.63 kg* | 0.16 | 6 |
| Nigeria | Shum-AS | as above | Sesbania grandiflora | 20 000 | corn,cowpe | 7.8 t | 0.49 kg* | 0.20 | 6 |
| Kenya | Shum-AS | 1300 mm Ferric Cambisol | Leucaena leucocephala | 10 000 | maize beans | 12 t<br>average | 1.2 kg | 0.23 | 16 |
| Kenya | Shum-AS | 1260mm Ferric Cambisol | Leucaena leucocephala | 50 000 | cassava | 24.8 | 0.35 kg* | 0.16 | 15 |

| Country | Type of AF-System | | | | | Continuous Supply | | Minimum area to supply 1 household (ha) | Ref |
|---|---|---|---|---|---|---|---|---|---|
| | Class | Rain/Soil | Tree | Tree density no/ha | Crops | t/ha | kg/tree | | |
| India | Shum-SP | Seasonal | Albizia lebbeck | 400 | pasture | 3.42 fuel<br>6.88 tot | 8.55<br>17.20 | 0.12<br>(0.41)a | 14 |
| India | Shum-SP | Seasonal | Albizzia procera | 400 | pasture | 2.79 fuel<br>6.68 tot | 6.79<br>16.70 | 0.13<br>(0.42)a | 14 |
| India | Shum-SP | Seasonal | Hardwickia binata | 625 | pasture | 2.78 | 4.46 | 0.30<br>(1.01)a | 14 |
| India | Shum-SP | Seasonal | Albizzia amara | 625 | pasture | 2.15 | 3.44 | 0.39<br>(1.31)a | 14 |
| Kenya | Shum-SP | 1260 mm Ferric Cambisol | Leucaena leucocephala | 50 000 | napiergras | 24.1 | 0.35 kg* | 0.17 | 15 |
| Kenya | Shum-SP | as above | Leucaena leucocephala | 50 000 | banagrass | 20.4 | 0.28 kg* | 0.20 | 15 |
| Mali | Shum-SP | 700 mm, Ferric Acrisol | Shrubs | 924-2142 | pasture | 0.2-0.6 | 0.2-0.3 | 5-13.4 | 22 |
| Ethiopia | Shum-SP | 600-900 mm Regosols, Fluvisols, Litosols, Cambisols | Acacia albida | 6<br>20<br>65 | pasture | 0.4<br>1.4<br>4.6 | 70* | 7.0<br>2.0<br>0.6 | 24 |
| Indonesia C. Java | Shum-ASP | Seasonal | Homegarden | 1053 | fruit, tubers, vegetables | 5.1 fuel<br>(7.6) tot | 3.39 kg*<br>(5.05) | 0.69<br>(0.46) | 19 |
| Indonesia C. Java | Shum-ASP | Seasonal | Homegarden | n.d. | fruit, tubers, vegetables | 7-9 | | 0.39-0.50 | 19 |
| Tanzania | Shum-ASP | 100-=1700 mm, Nitosols/Andosols | 14 different spp. | 65 | Banana, coffee + 13 spp. | 1.1-2.1 | 16.9-32.3 | 1.34-2.56 | 9 |

Notes AS = Agrisilviculture, AHS = Agrihortisilviculture, SP = Silvopastoral
* = Weight estimated assuming 700 kg/$m^3$
n.d. = No data
a = Figures in parentheses based on average consumption in region.
Numbers in reference column corresponds to numbers in Reference section.

### 2.2.2 Wood productivity by agroforestry system class and ecozone

Based on the system classification described above, average productivities for each category of system have been calculated and are presented in Table 5. The quite wide range of variation covered by the averages is also presented. The difference between systems in the humid and subhumid zone is clear for all three kinds of systems, with the productivity in the humid areas being 2-4 times higher. Within each zone the differences are less pronounced but agrosilvopastoral systems seem to have a lower average wood productivity, especially in subhumid areas. This may simply be because resources are divided between more components in this type of system.

**Table 5: Average and range of wood productivities in agroforestry systems (t/ha ± standard error of the mean)**

| Climate | | System components | | |
|---|---|---|---|---|
| | | AS | SP | ASP |
| Humid | Average | 14.1 ± 9.9 (n=11) | 19.5 ± 11.8 (n=6) | 12.9 ± 2.6 (n=3) |
| | Range | 3.5-42.3 | 5.4-58.5 | 10.2-15.4 |
| Subhumid | Average | 7.8 ± 6.3 (n=29) | 7.0 ± 8.4 (n=10) | 2.9 ± 3.6 (n=3) |
| | Range | 1.4-27.5 | 0.2-24.1 | 1.1-9.0 |

If the productivity data from the three different systems in the humid zone are compared statistically to their correspondents in the subhumid zone it can seen that the calculated means are significantly different. Most of the figures at the maximum end of the reported ranges relate to systems using very fast growing trees like *Leucaena leucocephala* and *Calliandra calothyrsus* at very high densities of up to 40,000 trees per hectare. Otherwise variation is due to numerous factors about which not all sources had information, for instance soil conditions, irrigation and fertilizers.

### 2.2.3 Land needs for woodfuel supply

By using the country specific rural household need for woodfuels presented in Chapter 1, the average minimum area of agroforestry land needed to supply the household with sufficient woodfuels has been calculated. For countries where reported consumption is markedly lower than the assumed actual need, e.g. India and Bangladesh, the average consumption for the region as a whole has been used instead. These results are presented in Table 6.

**Table 6: Minimum area of agroforestry system needed to supply one household with woodfuel (ha).**

| Minimum area in ha | | System components | | |
|---|---|---|---|---|
| Climate | | AS | SP | ASP |
| Humid | Average | 0.21 (0.27)# (n=11) | 0.20 (n=6) | 0.20 (n=3) |
| | Range | 0.06-0.8 | 0.05-0.49 | 0.15-0.26 |
| Subhumid | Average | 0.60 (n=29) | 0.59 (2.23)* | 0.95 |
| | Range | 0.08-2.01 | 0.17-13.4 (1.31)* | 0.39-2.56 |

Notes # If the least favorable cutting regime that required 0.8 ha, reported from Costa Rica, is included the average instead becomes 0.27 ha.
* If including the data from dry areas in Mali and Ethiopia.

In the humid zone the area needed is surprizingly similar for the three system categories, all requiring around 0.2 ha. In the subhumid zone the area needed is on average 3-5 times higher, with agrosilvopastoral systems having the largest average land requirements. These figures should be compared with the average land holding sizes that were presented in Chapter 1 (Table 2). Bearing in mind that these are average figures, it can be seen that <u>in the countries with a predominantly humid climate the area of agroforestry practice necessary to meet fuelwood needs is roughly equal to about 15 -30% of available agricultural land</u>. Since urban areas, which often include homegardens, are mostly not included in the category of agricultural land, the actual area needed may be even lower.

In Bangladesh the required land area could be in short supply, especially in drier areas, although the general high soil fertility in most of this country may produce higher than average yields. But the large number of farmers who have less than average sized landholdings, or none at all, would have to purchase their energy requirements. However, even farmers designated as landless in Bangladesh usually still have a homegarden (Abedin et al.,1990), which can supply part of their needs.

In India the area needed would amount to about 50% of average agricultural landholdings (assuming that all household energy requirements are met by woodfuels and the cowdung is instead used as fertilizer). Again the distribution of landholding sizes will mean that some rural dwellers must supplement their woodfuel production with purchased wood.

In the mountainous regions of Nepal and Bhutan, the high altitude areas, where productivity is lower, may not be able to supply sufficient woodfuels for average and below average sized landholdin-gs. In Nepal about 65% of woodfuels is estimated to originate from forests and in Bhutan the figure is probably even larger, although not precisely known (Ministry of Agriculture, Bhutan, 1991). When looking at the overalll forest situation in Bhutan this consumption does not pose any threat to forest resources in general at present, but problems may however exist at the local level. In Nepal considerable efforts are needed to ensure sustainability, like increasing wood productivity, diversifying energy sources, improving energy conservation etc.

In Pakistan about 27% of woodfuels is estimated to originate from forests. Recently a biomass survey including all woody vegetation was carried out in Pakistan, using satellite images, GIS and ground surveys (Archer, 1993). The biomass resources and productivity figures obtained were however subdivided by agro-ecological zones rather than specific vegetation types or management systems. It is therefore not immediately clear how large the wood resources are on farmlands.

For the remaining countries the data suggest that sustainable supply can be achieved through agroforestry practice on roughly between 25-50% of agricultural lands.

### 2.2.4 Individual tree productivity in different agroforestry system classes

For agroforestry systems with lower tree densities, it may be more relevant to look at the productivity of individual trees. This kind of data is presented in Table 7 and from those figures the minimum number of trees needed to supply the woodfuel demands of one household has been calculated and is shown in Table 8. Systems with tree densities higher than 2000 per hectare have been excluded from these calculations. These high densities are only possible on very short rotations before competition gets too pronounced or with very heavy pruning applied, like in alley cropping systems. Obviously there is great variation in growth and biomass of individual trees. The present figures are based on the various agroforestry systems listed in Table 4, consisting of young trees, i.e. with high growth rate but low total biomass as compared to mature natural forest.

**Table 7: Annual woodfuel production in kg per tree**

| Climate | | System components | | |
|---|---|---|---|---|
| | | AS | SP | ASP |
| Humid | Average | 26.9 | n.d. | n.d. |
| | Range | 12.5-54.3 | | |
| Subhumid | Average | 12.9 # (n=14) | 8.4 (18.7)* | 14.8 |
| | Range | 2.65-25.0 | 0.2-17.2 (70)* | 3.39-32.3 |

Notes # High density stands excluded (>2000 tree/ha)

- Including data on Acacia albida from Mali of 70 kg/tree

**Table 8: Minimum number of agroforestry trees needed to supply one household with woodfuel**

| Climate | | System components | | |
|---|---|---|---|---|
| | | AS | SP | ASP |
| Humid | Average | 137 (n=4) | n.d. | n.d. |
| | Range | 52-226 | | |
| Subhumid | Average | 283 (n=14) | 365 (n=5) | 309 (n=2) |
| | Range | 60-853 | 41-819 | 88-489 |

It has been reported that as little as 50-100 trees would be enough to supply, on a continous basis, the necessary fuelwood for one household (FAO, 1991). Although this seems to be theoretically possible for some agroforestry systems in the humid region, the present data indicates that on average a higher number is needed, ranging from averages of 140 trees in humid areas to almost 400 in subhumid areas. This will however mean that all individual trees should supply some wood for fuel which may not be possible in reality due to variations in specific properties, rendering some tree species either unwanted or unsuitable (see also below). Thus in general a higher average number of trees will be required, unless woodfuel production has a very high priority for the farmer.

*Figure 4: Agrosilvicultural system in La Nga, Vietnam.*

## 2.3 Factors influencing the actual woodfuel supply

Although conditions for tree growth may be potentially favorable in a given area and the supply could be as high as indicated in the data above, or even higher, a number of factors can be expected to counter the actual supply to various degrees. These factors are briefly discussed below.

### 2.3.1 Environmental conditions

Mature natural vegetation is a product of edaphic, climatic and biological conditions and may hence express the potential productivity of tree growing at that particular location without human interventions (MacDicken and Vergara, 1990). Although the potential dry matter production is much higher in the humid and subhumid (semiarid) tropics than in other climatic zones a number of constraints limit the actual production to levels lower than in temperate zones. This is partly due to the generally lower soil fertility and higher susceptibility to nutrient loss through erosion and leaching, because of the high intensity of rainfall, but also due to management practices and economic constraints (MacDicken and Vergara, 1990). In a cultivation situation one or more of these environmental factors may limit production, but may be overcome by wise management through fertilization, irrigation or by selective breeding/pest control, better financial support and training etc. However, today many other types of human activities are unfortunately also causing growing conditions for the vegetation to deteroriate by unwise or uncontrolled use of the environment, leading to erosion, reduced water supply, acidification of mangrove soils, pollution of soils and waters, etc. Reforestation and tree planting is generally regarded as able to alleviate some of these problems.

### 2.3.2 Species choice

Individual farmers and larger enterprises rarely grow trees with the sole purpose of supplying woodfuels (Dove, 1992). Mostly woodfuels originate from lopping, pruning or thinning operations or as leftover branches etc from timber harvest. Attempts to establish energy plantations have generally not been very successful. Therefore the wood producing capabilities is not likely to be the prime factor determining the farmers choice of tree species to grow. The tendency in recent decades among developers has been to focus promotion on a few tree species, more or less globally, often introduced in exchange for local species and/or provenances. The driving force in these choices very often seems to have been the sheer fact that the potentials of these species were already well described and hence they were considered "safe" choices by developers. However, these species may not always be well adapted to local conditions, like pests, as has been experienced with Leucaena and Azadirachta (neem) or to the management resources of the local farmers. Furthermore, people usually already have their traditionally preferred woodfuel species (Dove, 1992), whereas other species may be disliked because of smell, excessive smoke or other inconveniences. It may hence often be difficult, and at least requires some adaptation period, to introduce exotic species to the rural farmers and local species may be preferable in many cases. However, even within these limitations different qualities of the same tree species may be available for selection.

### 2.3.3 Production priorities

As was mentioned above, the systems for which productivity data are reported are not cultivated only with the purpose of producing wood for fuel. Even on a single species basis there are usually several products harvested by the farmers. The woodfuel productivity may thus to a large extent be governed by the perceptions and priorities of the farmer. This includes species choice, planting site and the subsequent management practices (see below). Since tree planting activities most often are the responsibility of the men (whereas woodfuel collection is carried out by women and children) there might not always be a direct relation between perceptions of the woodfuel situation and priorities for tree growing.

### 2.3.4 Management

Even with the optimal environmental conditions and species choice poor management can reduce the wood yield significantly. In relation to woodfuel supply the management practices most often influencing yield has to do with the timing and intensity of lopping, pruning, and thinning operations. Experiments on *Leucaena, Gliricidia, Sesbania* and *Erythrina* show that with increased frequency of pruning production of leaves (fodder/mulch) is raised but wood production is lowered (Duguma et al, 1988; Russo and Budowski, 1986), hence the objectives of management must be clear. Fertilizers, pesticides and irrigation are rarely applied to trees, at least not by rural farmers. However, since such technologies are often applied in experimental plots, some of the productive figures presented above should be viewed with that caution in mind.

### 2.3.5 Socio-economic factors

Very often the resources of the average small farmer in terms of cash, land, education and time may limit the choice, establishment and management of trees. With few possessions and no land title (see also below) as collateral, farmers have difficulties in obtaining favorable loans from commercial banks for investment in seedlings, fertilizers, pesticides or other improvements. More often they have to rely on private money lenders charging very high interest rates and hence may quickly end up in a situation where the money lender dictates what crops to grow. This is more likely to be fast growing cash crops than trees. In the case of limited workpower within the family, priority will usually be given to the cultivation of food crops (Dove, 1992). In situations were woodfuel trade can provide a (quick) cash income for purchasing immediate household needs woodfuel may, however, receive a higher priority.

### 2.3.6 Infrastructure and distribution

Since woodfuel supply may vary considerably between areas within the same country, a trade flow from surplus areas to deficit areas is a natural market adaption to the situation. This however requires that adequate and economical transport is available, which may not always be the case. Hence, surplus wood can not be made available in deficit areas and no income can be earned from sales of surplus woodfuel production. Even though good roads may exist, the high cost of transportation can impede the flow of woodfuels. The processing of wood into charcoal, if properly carried out, increases the energy content per unit volume by a factor of four. Since charcoal can obtain a higher price than fuelwood it is economically possible to transport it over longer distances.

### 2.3.7 Policies and legislation

One of the most commonly mentioned obstacles to the promotion of tree growing is the question of land tenure. Although many farmers may have farmed their lands for decades they have never acquired a legal land title deed. Very often they are actually occupying state forest land, or actual land boundaries may be very poorly demarcated, if marked at all. This constant uncertainty about possible reclamation of the land by the forest department and the fact that a too conspicuous number of trees would (re)classify it as forest land, makes farmers reluctant to invest in tree planting that will only give a return after several years. Even in many land allocation schemes land rights are only granted for a limited period and hence do not properly encourage farmers to practice sustainable land use. This problem also partly applies to farm-labourers who farm land for absentee landlords, e.g in South Asia.

In several countries legal restrictions impede the development of small-scale tree-based enterprises, for instance charcoal trade. These restrictions were imposed following the earlier belief that woodfuel gathering was a major cause of forest destruction. Most often these regulations limit the amount of charcoal that can be transported without a special license. This license, or alternative unofficial fees, may be a major obstacle for the small farmer.

## 2.4 Optimizing woodfuel production

By alleviating any of these limiting factors improved production is possible. An obvious precondition is of course that the farmer actually wishes to produce more wood for fuel. In the following section some, primarily technical, approaches to improving production are discussed.

Of prime importance is the choice of species to grow. Since in most cases the farm will already be planted with some trees, introduction of other species needs to be gradual in order to avoid a gap in the supply of tree products. The introduction of exotics may be very tempting but requires careful consideration and consultation with farmers to avoid failures. A large scale failure may cause a serious confidence gap between farmers and extension workers. It should be remembered that fast growing species grown on short rotations have a lower wood density and burn quickly hence making them less convenient for many cooking purposes. Superior species/provenances of local origin may thus produce better average results, but can gradually be supplemented with exotics when these have already proven their suitability to the area. If using local breeding material, vegetative propagation with material from superior mother trees is generally preferable because of the large natural genetic variation in offspring propagated from seeds. For larger scale applications seed propagation may be necessary because of insufficient vegetative breeding material. Because the calorific content can vary a lot this quality should generally not play as large a role in the choice of species as other qualities like productivity, environmental and cultural suitability etc. (Harper et al, 1982).

Fertilization and irrigation can often increase the yield considerably, but generally require investment resources not available to the average small farmer or, if available, will be confined to agricultural crops with more immediate return. The use of nitrogen fixing trees is strongly recommended because these can overcome limitations in soil nitrogen resources and accompanying crops will benefit also. For the selection of nitrogen fixing tree species the reader is recommended to consult MacDicken (1994). However, other elements, especially phosphorus, may also limit production. Organic fertilizers of various types may be available, or even grown for that purpose, e.g. leguminous cover crops, weeds used as mulch or animal dung.

It has already been mentioned that the frequency and intensity of pruning, pollarding and lopping will affect the distribution between leaf biomass and wood biomass subsequently produced. The higher the cutting frequency, the more leaf biomass is produced at the expense of wood biomass. The experiments reported in general have shown that pruning intervals shorter than one year produce significantly lower wood yields and at three monthly intervals wood yields are almost negligible. Since the farmer needs woodfuels continuously all year round it is thus better to rotate the cutting, thereby allowing for longer intervals to individual trees.

Weeding is important around the seedlings, particularly during the initial establishment of trees. At later stages the shading from the trees themselves will limit weed growth. The weeds may be used as fodder or mulch.

In an agroforestry system the objective is to optimize the total output of the different products and although crops may benefit each other, it is not possible to obtain maximum productivity of all individual species. In some cases lowering the tree production in order to increase the production of other crops may be desired. Apart from reducing the number of trees this can be obtained by root pruning, reduced fertilization or watering or by other means. Naturally an increase in woodfuel production should not be at the cost of essential subsistence food crops of the farmer.

The reader should also consult Burley & Stewart (1985) and Forestry/Fuelwood Research & Development Project (1992) for further guidelines on the subject.

*Figure 5: Homegarden north-west of Chiang Mai, Thailand*

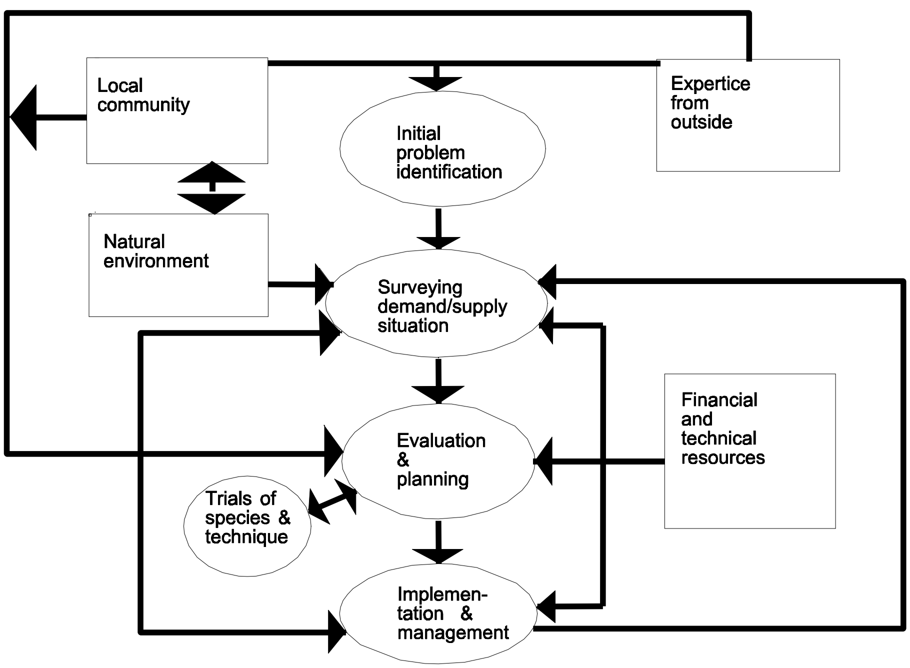


*Figure 6: A possible framework for woodfuel evaluation and planning.*

# 3. EVALUATING AND PLANNING WOODFUEL SUPPLY FROM AGROFORESTRY SYSTEMS

This section does not intend to give a thorough treatment of biomass estimation, land use evaluation or energy planning, but merely attempts to introduce the subject in relation to the information in the previous chapters as well as guide the reader to more detailed sources of information. A possible general framework for woodfuel evaluation and planning is shown in Figure 6. Some of the steps in this process are discussed in more detail below.

## 3.1 Evaluating woodfuel energy needs

The first step in a woodfuel planning or assessment process will be to assess the current energy needs and may include estimates of future needs as well. The consumption/demand figures described previously were average figures, in some cases covering quite wide ranges of local variation. They may, however, serve as initial guidelines or reference points, but should preferably be supplemented with estimates from the survey area itself. Important local factors to notice could be: low temperatures, large family sizes, inefficient stoves and cooking habits, wood-using small-scale industries etc., all of which may cause above average demands. Availability of cheap fuel alternatives (e.g LPG) may on the other hand lower the demand. The surveyor should also be aware of marked seasonal differences (wood has higher moisture content in the wet season, hence requirements are higher). As was emphasized in Chapter 2 it is also important that the woodfuel production is not viewed in isolation from the cultivation of other crops since they are interdependent.

Most previous quantifications of woodfuel use have been based on information obtained through interviews rather than actual measurements. Although this may be reasonably precise if the farmer keeps a very good "record" of his woodfuel consumption or production, such farmers are very rare, if they exist at all. Since the amount of wood used will also vary throughout the year depending on season (Koopmans, 1993), an "on the spot" recall may be misleading. Occasionally interviews are combined with actual measurements of "today's consumption" or fuelwood stacked for later use: "How long will this stack last?" Since there is considerable variation in wood moisture content, wood densities and actual wood volume in a stacked cubic meter, this procedure may not improve the estimates much. Measuring all fuelwood used is obviously not practical either, but interviews should be combined with precise field measurements of the weight of wood used during a specified period and small sub-samples of this wood for subsequent drying and weighing. In this way a "correction factor" can be applied to the weight measurements obtained in the field and greater accuracy obtained. Lower levels of accuracy may be acceptable if the results are only intended for local use, but as soon as data are intended to be extrapolated to represent larger areas, greater accuracy is crucial. Some general ways to improve the precision of fuelwood consumption data are listed below:

1) Combine users accounts with actual measurements
2) Increase sample size by:
    a. Increasing length of study period
    b. Conduct repeated sample visits
    c. Increase number of households sampled
3) Stratify sampling to cover different seasons, if necessary.
4) Take sub-samples of wood for oven-drying (48 h at 80-100°C) in order to correct for moisture content.

How to design and implement a survey depends on the objectives of the survey, the situation in the survey area as well as the available resources for collecting and analyzing the data. Unfortunately, the available resources are most often the factor limiting the extent of the survey. In any case it is crucial to involve the community right, from the beginning to establish whether there is a perceived woodfuel problem at all among community members. This may sound superfluous but examples of community woodlots established and never used except by the researcher who established it has been reported (Tingsabadu et al.,1987). It is not within the scope of this paper to give detailed descriptions or recommendations for survey methodologies, like Rapid Rural Appraisal or Participatory Rural Appraisal and the reader should consult the numerous publications that deals with this subject in detail, for instance FAO/SIDA (1983), Khon Kaen University (1987) and FAO (1990).

## 3.2 Estimating woodfuel resources

After the woodfuel needs of an area have been determined, the existing supply must be realistically assessed in order to plan for future supply.

### 3.2.1 Estimating biomass

Fairly accurate volume/yield tables have been developed for most temperate types of forest stands, which are mostly monoculture plantations, and also for a large number of tropical plantation scenarios, including some volume regressions for natural forest stands. Many of these equations only consider the commercial part of the trees, namely the stem or bole, measured from ground (cutting) level to first major branch. Trees in agroforestry systems though, are in many cases subject to conditions quite different from a plantation or natural forest situation. Generally, the distance between the individual trees is larger and hence they develop morphologically differently, usually showing more extensive branching and crown development. The crown normally constitutes between 30 and 50% of total wood biomass. The higher proportion of biomass allocated to branches is interesting from a woodfuel producers point of view, since it is branches that are most often used for woodfuels. This morphological trend is less pronounced the higher the tree density is and may approach natural forest conditions in some homegarden systems and village forests, where trees are allowed to reach a higher age and size. Alley cropping systems present a special case where "trees" are cultivated at very high densities but kept small by frequent pruning and the system bears little resemblance to actual forests.

When pollarding is practiced, trees may develop multiple stems. Furthermore, management practices like lopping and pruning may add to the "atypical" tree growth, making standard forest mensuration impossible. A much more flexible approach is thus necessary in dealing with estimates of woody biomass in agroforestry systems. Measuring stem volumes, even on multi-stemmed trees, is fairly simple, whereas determining crown biomass can be very difficult. Some "destructive" sampling of a number of trees may be necessary, although this can be unacceptable in on-farm measurements. An estimate based on normal stem to crown volume ratios for the particular species can be an acceptable solution if such figures are available. The reader is recommended to consult MacDicken et al (1991) for specific measurement and calculation methods to apply to multipurpose trees and shrubs.

### 3.2.2 Estimating productivity

The productivity ranges reported for different agro-ecological zones and system categories in Chapter 2 may serve to provide a preliminary idea about what can be achieved. In case of closer similarity to one of those specific systems listed in appendix A, the expectations may be more firmly based on those productivity figures, but reference should be made to the numerous factors that can determine the actual production (section 2.3).

In general, non-destructive measurement methods must be applied in on-farm measurements, whereas destructive measurements may be applied in some research situations, or whenever wood is actually harvested by the farmer. Whatever approach is chosen it is important that standard methodologies and definitions are used consistently. The same definitions for what is a stem, tree height, diameter at breast height etc. must be applied at all times and must be precisely recorded for later reference. This requires training and discipline by the survey team. Measurement of standing biomass must be carried out at least twice in order to determine growth. Rather than measuring tree growth, measuring actual harvest may be more relevant, although difficult outside research plots unless very good cooperation with farmers can be established. In this way it may be ensured that only those wood parts that the farmer actually uses for fuel are included in estimates. In destructive measurements a consistent methodology is equally important, especially regarding drying and weighing of wood samples. Some very useful practical guidelines to solve these technical problems have been thoroughly dealt with by MacDicken et al. (1991).

## 3.3 Local level planning

As mentioned above, early involvement of the community members is a prerequisite for success. This in particular applies to the planning of any future changes of the community, which the measures taken will  inflict. It must be recognized by all parts that there is a woodfuel issue. The overall policies governing (wood)energy and community development, if existing, would provide the framework within which the planning process can take place. This should be a continuous process, allowing for dialogue and adjustments along the way. As well as involving the community members themselves both sociological and technical expertise should be involved in surveying and planning since neither of these fields is sufficient on its own and must supplement one an other in order to cover all aspects of the village situation.

### 3.3.1 System and species selection

Although on-the-site tests to determine which species, systems and management practices to apply is clearly preferable, this requires considerable time, and figures may be found in Tables 4 - 8 to guide the initial selection and planning process. The area or number of trees required by different types of system in different agro-ecological zones to supply a given size of rural population, can be approximated from Tables 7 and 8 and thus be used to guide the proper allocation of land and the choice of agroforestry system for the specific situation. The initial plan should also be made in accordance with local conditions, like slope, soil type etc. and if necessary, should subsequently be modified along the way according to the results of field trials and other experiences.

No specific species can be recommended in general here, since this will greatly depend on local conditions. Some general criteria for selection should be:

- Tolerance to local environment (climate, soils, pests)
- High productivity
- High pruning tolerance
- Good burning properties (low moisture, low ash & sulphur content, high density, no sparks)
- Easy propagation and management

Useful information on specific species can be found in NAS (1980 and 1983) and in ICRAF's "Multipurpose Tree and Shrub Database". Calorific values should in general not be a major determining criterion for species choice due to the large variation even within the same species, but comprehensive information on this subject for more than 400 species is reported in Harper et al. (1982).

## 3.4 Large scale planning

Planning or evaluation of woodfuel supply at a regional or national level will basically require the combining of local data into an overall picture. Since the existence of large local variations have already been described it is important not just to multiply data from a few localities that may be non-representative to a larger scale. Ideally, the process should rather involve the addition of data from individual villages or districts, although in practice that amount of data is rarely available. By a zonation or grouping of the sub-components into larger units of a similar nature, data can be multiplied within each of these groupings and then the totals of the zones can be added up. This was basically the approach followed by the global FAO woodfuel survey in the early 80's (FAO, 1983). Soussan et al (1992) proposed a topology approach, based on the assumption that the fuelwood situation in developing countries can be divided into types of areas with quite similar environmental and socio-economic conditions, and hence requires similar measures of action.

Manual treatment of large amounts of data can soon become very cumbersome and costly and hence impracticable. Fortunately, a number of computerized tools have become available recently at progressively lower cost and with a higher degree of user friendliness than hitherto.

### 3.4.1 Data handling and planning tools

A number of computer programs, some of which are also applicable to PCs, are now available and can significantly ease the treatment of data and the planning process. This includes a number of energy planning programs of which only LEAP, which is probably the only one at present that can fully incorporate wood and biomass energy, will be mentioned here. The Long-range Energy Alternatives Planning system (LEAP) was originally developed as part of the Kenya Fuelwood Project (1980-82) but has since been further developed by the Stockholm Environment Institute - Boston to include other energy sources, more advanced features and an environmental database supplied with the assistance of United Nations Environment Programme (UNEP) (Stockholm Environmental Institute - Boston, 1992). It is mainly a simulation program and is particularly useful for the evaluation of different planning options using LEAP's scenario programs. After estimating future energy demands, different approaches to meet these needs can be simulated and their effectiveness as well as environmental impact, as far as these can be quantified, can be evaluated. A weakness of these kind of computer programs is that factors of a political, social, cultural and in some cases environmental, nature, can be difficult to quantify and hence cannot be properly considered by these programmes.

Experiences with the use of LEAP have shown that the major obstacle to its use is the lack of primary data (Oosterveen, 1993).

Geographic information systems (GIS) can also further aid the planning process. These systems allow for all sorts of combinations of spatial geographical data with demographic, economic, political, environmental and other data into large scale analysis or simulations to evaluate the effects of various development scenarios. This allows planners to take the often large local variation in woodfuel situations in developing countries into account. Their use requires the availability of maps and other geographical data in a digitized form. These can be prepared from existing maps or now more commonly from remote sensing data (satellite or air photos). As soon as these basic data are entered into the database it can be progressively expanded with additional types of information, whenever these become available, and allow for increasingly more complex analyses. The ability to simulate various development options or environmental scenarios makes GIS a very useful and cost effective planning tool. Manual calculations of a similar scale and quality would be largely impossible in practice.

GIS and planning programs like LEAP are not mutually exclusive, but could very well complement each other. Some activities in this field are currently going on, for example at RWEDP where ways to combine these two types of programmes are being explored.

<u>A word of caution</u>: High tech computer graphics may look very "convincing and credible" but it should be remembered that the results produced are no better than the data that are entered in the first place and it better than the people who handle and interpret them. The importance of accurate primary data and trained personnel must be stressed.

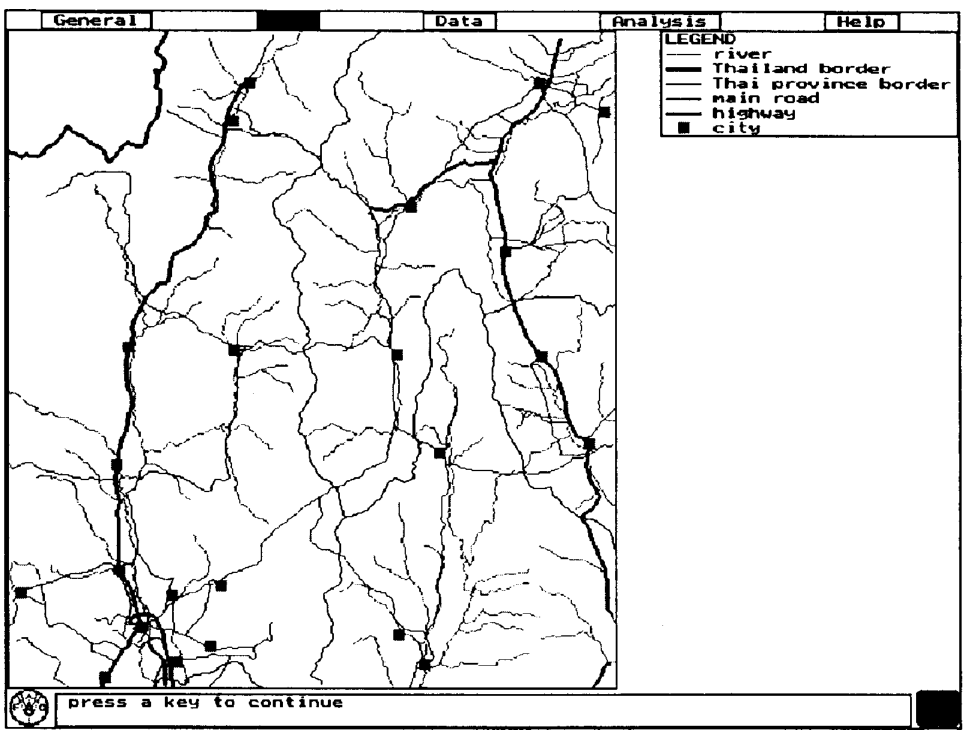


*Figure 7: GIS - a useful tool for land use planning*

## 4. CONCLUSIONS

Although the available information on agroforestry land use and woodfuel supply are somewhat scattered and sometimes indirect, there are strong indications that agroforestry systems are probably already a very important woodfuel supplier and definitely have the potential to meet the woodfuel demands in most of the Asian countries. The present initial data suggest that this would be possible if farmers adopted appropriate agroforestry practices on 20-30% of their agricultural landholdings on average in humid zones and on 25%-50% in drier areas. In some countries, like Pakistan, Nepal, India and Bangladesh it is less certain whether this proportion is sufficient and even more land may have to be planted with trees. In addition, productivity must either be improved or alternative sources of wood sought. It would be very useful to get more specific data on agroforestry land use and productivity from these areas in particular, but in general more research on the subject to confirm the initial indications presented here is necessary.

In general, the extent and kind of agroforestry land use is very poorly known and national agricultural and forestry land use statistics should be adapted to this need. Remote sensing is a quick and cost effective way of obtaining some of these data. Such an improved database would enable much more reliable evaluation and planning of the supply of woodfuel, which is still the major energy source for the majority of the third world population that are living in rural areas. But remote sensing data alone can not tell us anything about land ownership and access to fuelwood, and therefore must be combined with data obtained from ground surveys.

On average most countries have enough land to ensure fuelwood supply through agroforestry practice, but because of the very uneven distribution of landholding sizes in some countries woodfuel may not become available to everybody despite sufficient average production. Policy makers and planners should take care that this weak group is ensured supply through communal tree plantings, land (re)allocation or other means.

Limitations in infrastructure may similarly hinder the distribution of wood from surplus areas to deficit areas. Here woodfuel problems could also be addressed through improvements in infrastructure.

Fuelwood issues should also be recognized and addressed by the agricultural sector, since the majority of fuelwood originates from agricultural land, but no policies or planning for its production exist at present.

As woodfuel and other biomass is the major energy supplier in many countries, the energy sector needs to incorporate it and its sources much further into energy policies and planning. Woodfuel use may be regarded as backwards by many, but as a renewable, "$CO_2$-neutral" energy source it could also be regarded as more "modern" than fossil fuel sources.

Since woodfuel issues accordingly require the involvement of both the agricultural, energy and forestry sector these should engage in much closer cooperation regarding biomass fuels to ensure a balanced and complete woodfuel development process. At present it is normally only the forestry sector that is responsible, but this department has limited expertise in energy issues and no authority on agricultural lands, where the majority of woodfuel originates.

Encouragement of (local) charcoal production will create a product that can be economically transported over longer distances, is more convenient to use and can generate jobs in charcoal processing and trade. In many countries legislation prohibits this development, probably as a remnant of the belief that woodfuel collection is a major cause of forest destruction. This legislation should be reconsidered. A strengthening of charcoal processing and trade would also serve to bring woodfuels into the formal economy thereby increasing its "visibility".

The data on average productivity presented in this paper may serve as an initial basis for policy formulation, whereas the more system specific data may be used for initial local level planning. As the wide range of the data indicates, locally relevant information should be gathered in any case and the villagers should be involved in this process as well as in further planning.

Efficient computerized planning tools are available to combine and analyze a large amount of data and evaluate various development options before major policy decisions are made. However, the availability and accuracy of primary data is still the biggest limitation to this process and should be improved first.

*Figure 8: Agrisilviculture, La Nga, southern Vietnam.*

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## Appendix A:
## Trees listed as woodfuel suppliers in ICRAF Multipurpose Tree and Shrub Database

*Acacia auriculiformis*
*Acacia catechu*
*Acacia decurrens*
*Acacia holosericea*
*Acacia leucophloea*
*Acacia mearnsii*
*Acacia modesta*
*Acacia nilotica ssp. nilotica*
*Acacia nilotica ssp. indica*
*Acacia nilotica var. adansonii*
*Acacia planifrons*
*Acacia senegal*
*Acacia tortilis*
*Acacia tortilis ssp. raddiana*
*Acer caesium*
*Acrocarpus fraxinifolius*
*Adenanthera pavonina*
*Aegle marmelos*
*Aesculus indica*
*Ailanthus altissima*
*Ailanthus excelsa*
*Aisandra butyracea*
*Albizia amara ssp. sericocephala*
*Albizia chinensis*
*Albizia lebbeck*
*Albizia odoratissima*
*Albizia procera*
*Alnus nepalensis*
*Alnus nitida*
*Anacardium occidentale*
*Anisophyllea laurina*
*Annona muricata*
*Anogeissus latifolia*
*Anogeissus pendula*
*Areca catechu*
*Artocarpus heterophyllus*
*Artocarpus integer*
*Artocarpus lakoocha*
*Atriplex nummularia*
*Avicennia marina*
*Avicennia officinalis*
*Azadirachta indica*

*Balanites aegyptiaca*
*Bauhinia purpurea*
*Bauhinia vahlii*
*Bauhinia variegata*
*Berrya cordifolia*
*Betula alnoides*
*Bombax ceiba*
*Borassus aethiopum*
*Borassus flabellifer*
*Bridelia retusa*
*Broussonetia papyrifera*
*Bruguiera gymnorrhiza*
*Butea monosperma*
*Buxus sempervirens*

*Caesalpinia coriaria*
*Calligonum polygonoides ssp. polygonoides*
*Calotropis procera*
*Capparis decidua*
*Carissa spinarum*
*Cassia auriculata*
*Cassia fistula*
*Cassia siamea*
*Castanopsis indica*
*Castanopsis tribuloides*
*Casuarina cunninghamiana*
*Casuarina equisetifolia*
*Cedrela serrata*
*Ceiba pentandra*
*Celtis australis*
*Ceratonia siliqua*
*Ceriops tagal*
*Ceriscoides turgida*
*Citrus aurantium*
*Citrus paradisi*
*Citrus reticulata*
*Citrus sinensis*
*Cocos nucifera*
*Codariocalyx gyroides*
*Colophospermum mopane*
*Cordia dichotoma*
*Corylus colurna*
*Cotoneaster bacillaris*
*Crataegus laevigata*
*Crateva adansonii*

*Dalbergia melanoxylon*
*Dalbergia sissoo*
*Delonix elata*
*Dichrostachys cinerea*
*Dillenia pentagyna*
*Diospyros Lotus*
*Diospyros melanoxylon*
*Dodonaea viscosa*

*Elaeagnus umbellata*
*Elaeocarpus serratus*
*Eriobotrya japonica*
*Erythrina abyssinica*
*Erythrina variegata*
*Eucalyptus camaldulensis*
*Eucalyptus citriodora*
*Eucalyptus tereticornis*

*Feronia limonia*
*Ficus auriculata*
*Ficus benghalensis*

*Ficus carica*
*Ficus neriifolia*
*Ficus palmata*
*Ficus religiosa*
*Ficus retusa*
*Ficus rumphii*
*Ficus virens*
*Flacourtia indica*
*Flemingia macrophylla*
*Fraxinus excelsior*
*Fraxinus floribunda*

*Garcinia mangostana*
*Gardenia latifolia*
*Garuga pinnata*
*Gliricidia sepium*
*Gmelina arborea*
*Grevillea robusta*
*Grewia elastica*
*Grewia optiva*

*Hardwickia binata*
*Hibiscus tiliaceus*
*Holarrhena antidysenterica*
*Holoptelea integrifolia*

*Juglans regia*
*Juniperus procera*
*Justicia adhatoda*

*Kydia calycina*

*Lagerstroemia parviflora*
*Lannea coromandelica*
*Leucaena leucocephala*
*Leucaena leucocephala k28*
*Leucaena leucocephala Peru, k6*
*Leucaena leucocephala k8*
*Litchi chinensis*

*Macaranga peltata*
*Madhuca longifolia*
*Mallotus philippensis*
*Mangifera indica*
*Manilkara zapota*
*Maytenus heterophylla*
*Melia azedarach*
*Mitragyna parvifolia*
*Moringa oleifera*
*Morus alba*
*Morus serrata*

*Neolamarckia cadamba*
*Nyctanthes arbor-tristis*

*Olea europaea ssp. cuspidata*
*Ougeinia oogeinensis*
*Parkinsonia aculeata*
*Parrotia jacquemontiana*
*Paulowina elongata*
*Paulownia tomentosa*
*Phyllanthus emblica*
*Pinus roxburghii*
*Pinus wallichiana*
*Pistacia chinensis*
*Pithecellobium dulce*
*Platanus orientalis*
*Pongamia pinnata*
*Populus ciliata*
*Populus deltoides*
*Populus euphratica*
*Populus nigra*
*Premna bengalensis*
*Prosopis cineraria*
*Prosopis farcta*
*Prosopis juliflora*
*Prunus armeniaca*
*Prunus cerasoides*
*Prunus padus*
*Psidium guajava*
*Punica granatum*
*Pyrus pashia*

*Quercus dilatata*
*Quercus glauca*
*Quercus ilex*
*Quercus leucotrichophora*
*Quercus semecarpifolia*

*Rhizophora mucronata*
*Rhododendron arboreum*
*Rhus abyssinica*
*Ricinus communis*
*Robinia pseudoacacia*

*Salix alba*
*Salix babylonica*
*Salix elegans*
*Salix purpurea*
*Salix tetrasperma*
*Salix triandra*
*Salix viminalis*
*Salvadora oleoides*
*Salvadora persica*
*Sapindus mukorossi*
*Sapium sebiferum*
*Schima wallichii*
*Schleichera oleosa*
*Sesbania bispinosa*
*Sesbania cannabina*
*Sesbania formosa*
*Sesbania grandiflora*
*Sesbania sesban*
*Shorea robusta*
*Sonneratia caseolaris*
*Spondias pinnata*
*Stereospermum chelonoides*
*Syzygium cumini*

*Tamarindus indica*
*Tamarix aphylla*
*Tecomella undulata*
*Tectona grandis*
*Terminalia alata*
*Terminalia arjuna*
*Terminalia belerica*
*Terminalia chebula*
*Terminalia paniculata*
*Thespesia populnea*
*Toona ciliata*
*Trema orientalis*
*Trema politoria*

*Ulmus procera*

*Vitex negundo*

*Wrightia tomentosa*

*Zanthoxylum armatum*
*Ziziphus mauritiana*
*Ziziphus nummularia*
*Ziziphus xylopyrus*
*Ziziphus zizyphus*

## APPENDIX B:
## Energy Units and conversion factors

TOE = ton of oil equivalent
TCE = ton of coal equivalent
BOE = barrels of oil equivalent
BTU = British Thermal Unit

**The energy content of one ton of fuelwood is equal to:**

14,235 MegaJoule *
0.335 ton of light fuel oil
2.800 BOE
0.313 ton of liquified petroleum gas (LPG)
0.486 ton of hard coal
0.680 ton of brown coal
0.417 ton of natural gas
0.491 ton of charcoal
0.919 ton of cereal straw
1.186 ton of dried dung cake
0.795 ton of coconut shells
0.98  ton of air dry rice hulls
0.92  ton of maize cobs
0.860 ton of cotton stalk

One PetaJoule = 23,900 TOE = 70,300 ton of fuelwood

* Average figure. Fresh cut wet wood 10,900 MJ/ton; air dry in humid zone 15,500 MJ/ton; oven- dry 20,000 MJ/ton. See also Harper et al (1982)