AGRICULTURAL AND FOREST RESIDUES - GENERATION, UTILIZATION AND AVAILABILITY[1]

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1. Introduction

Biomass energy is an important source of energy in most Asian countries. Substantial amounts of fuelwood, charcoal and other biomass energy such as agricultural residues, dung and leaves are used by households and industries. The main household applications are cooking and heating whereas industrial applications range from mineral processing (bricks, lime, tiles, ceramics), food and agro processing, metal processing, textiles (dyeing, etc.) to miscellaneous applications like road tarring, tyre retreading, and ceremonies. Besides these ‘heating’ applications, biomass fuels are also used for power generation, for example the widespread use of bagasse in the sugar industry (steam and electricity) and oil palm residues (steam and electricity).

A lot of biomass fuels are available as by-product from other activities, such as saw milling and agricultural crop production. This document provides an overview of estimates on the production of such residues as well as some rough estimates of other uses (actual and potential) for such residues.

Chapter 2 describes the types of biomass residues for major sources and provides estimates for the yield of residues. Chapter 3 gives information of current end uses for the main residues, apart from energy applications. Annex 1 gives an overview of various estimates for yields of crop residues as available from literature, in the form of so-called Residue-to-Product-Ratios (RPR), as well as composition, moisture content and ash content. Annexes 2a and 2b gives an estimate of the amount of crop and wood residues generated in 1997 in RWEDP member countries.

2. The Resource Base

In order to be able to evaluate the sustainability of present consumption patterns and the feasibility of introducing modern biomass fuel-based applications, an assessment of the resources and its availability for energy has to be made. Below, an overview of the resource base for different types of residues is given. It should be noted that this overview only considers:

- wood residues from logging and wood-processing such as saw-milling and manufacturing of plywood and particle board;
- wood residues generated by management of perennial crop plantations such as pruning and replanting of trees (rubber, coconut, palm oil);
- crop residues generated by agricultural production.

The overview <u>does not include</u> woodfuels obtained directly from:

- Forests, e.g. clearing of forest lands for agricultural purposes, cutting or lopping trees purely for fuelwood, collecting deadwood;
- Trees growing on agricultural land, communal lands, on waste lands, on private land such as home gardens, trees growing along roads, etc.

It should also be noted that the information provided here, <u>only shows the gross amount of residues, which are generated in theory. In practice this amount is normally not available</u>. This is due to a variety of reasons such as for instance use as raw material for non-energy purposes, or being non-recoverable. Conversely, residues may be available but there may not be potential users.

2.1 Forest- and Wood Processing Residues

2.1.1 Logging residues

Recovery rates vary considerable depending on local conditions. A 50/50 ratio is often found in the literature e.g. for every cubic meter of log removed, a cubic meter of waste remains in the forest (including the less commercial species). In case logging is carried out for export purposes, values of up to 2 cubic meter of residues for every cubic meter of log extracted may be valid (Adams, 1995). Other sources (e.g. Forest Master Plan for Indonesia – GOI, 1990) give a ratio of 60/40 e.g. 6 cubic meters of logs versus 4 cubic meters of waste remaining in the forests. The 40% consists of 12% stemwood (above first branch), 13.4% branch wood, 9.4% natural defects, 1.8% stemwood below first branching, 1.3% felling damage, 1.6% stump wood and 0.5% other losses.

Figures of 30% logging wastes have been reported from Malaysia (FRIM, 1992) but others (Jalaluddin et. al. 1984) indicate a recovery rate of 66% with 34% being residues, consisting of stumps, branches, leaves, defect logs, off-cuts and sawdust. This figure may be higher if unwanted species that are felled intentionally or accidentally are considered as well. Most of the wood residues are left in the forest to rot, in particular in sparsely populated areas where demand for woodfuels is low. In some cases the residues are converted into charcoal. In order to calculate the amount of logging residues an average recovery factor of 60% has been used.

2.1.2 Saw-milling

Recovery rates vary with local practices as well as species (FAO, 1990). After receiving the logs, about 12% is waste in the form of bark. Slabs, edgings and trimmings amount to about 34% while sawdust constitutes another 12% of the log input. After kiln- drying the wood, further processing may take place resulting in another 8% waste (of log input) in the form of sawdust and trim end (2%) and planer shavings (6%). For calculation purposes a yield factor of 50% has been used (38% solid wood waste and 12% sawdust).

2.1.3 Plywood production

Plywood making is a large-scale operation and involves the cutting of the logs to the length required and debarking the logs. After the preparatory operations, sizing, debarking and cleaning, the logs are sliced i.e. the logs are rotated in a machine. While rotating, a knife slices or peels off the veneer. Then the sliced veneer is cut into the size required and it is dried after which it is ready for further processing. The dry veneer slices are sorted, with sheets having holes or other irregularities being rejected. The sheets are glued and hot-pressed into plywood sheets. Finally, the plywood sheets are trimmed (cutting into standard sizes), sanded and graded.

Recovery rates vary from 45 to 50% with the main variable being the diameter and quality of the log. Of the log input, the main forms of waste are log ends and trims (7%), bark (5%), log cores (10%), green veneer waste (12%), dry veneer waste (8%), trimmings (4%) and rejected plywood (1%). These form the largest amount of waste while sanding the plywood sheets results in another loss of 5% in the form of sander dust (FAO, 1990). For calculation purposes a yield factor of 50% has been used, with 45% solid wood residues and 5% in the form of dust. However, higher recovery rates have been found in literature and a figure of 54% has been reported as being the average for Indonesian plywood factories (Weingart et al, 1988).

2.1.4 Particle board production

Particleboard production basically involves size reduction of the wood, drying, screening, mixing with resins and additives, forming of the so-called mat, pressing and finishing. All types of wood are used for the production of particle board such as solid wood, solid wood residues (off cuts, trimmings), low grade waste such as hogged saw mill waste, sawdust, planer shavings, etc. During the production process about 17% residues are generated in the form of trimmings. However, this amount is recycled. In addition about 5% screening fines and about 5% sanding dust is generated as residues which is mainly used as boiler fuel for process steam generation (FAO, 1990). For calculation purposes a residue factor of 10% has been taken, consisting of screening fines and dust while 17% of the residues are assumed to be recycled.

2.2 Perennial Plantation Crop Residue

Perennial crop plantations such as for coconut and rubber generate considerable amounts of wood residues from pruning and replanting activities. A few of the perennial plantation crops will be covered here. Two different methods can be used to calculate the amount of residues generated. The first one, often used for woody residues from perennial crops, is based on the cropped area. This method assumes that tree crops grow with a more or less standard planting density, which in practice may not be true. The type of management (traditional or advanced) as well as the crop variety (local variety, improved and/or clonal variety) can result in large differences in the amount of crop as well as residue obtained from a particular cropping area.

The second method, often used for annual crops, is to use a residue to product ratio (RPR). With this method the amount of residues is calculated from the crop production using an average RPR value. This method enables the calculation of the amount of residues in multi-cropping systems as more than one crop may be grown on a certain area within a one-year period. However, this method has the drawback that different crop varieties may have different RPR values (possibly even from year to year) which is caused by variations in weather, crop type grown, water availability, soil fertility, farming practices etc. Besides, in many cases the moisture content of residues is not given when reporting RPR values. Since moisture content can vary widely between fresh and air-dry biomass (differences of up to a factor of 3 in the case of bagasse), estimating the amount of residues using an RPR may result in inaccurate estimates. Annex 1 provides an overview of RPR data as available from various publications. It is obvious from the overview that there are large variations and therefore, due care should be taken in using RPR values. The same applies to using average values for residue-to-cropping-area. Where possible, field checks should be carried out to determine the most appropriate value for a given crop and area. Below, estimates of RPR values for different crops are given, used by RWEDP to calculate the amounts of residues generated in the RWEDP member countries (see Annex 2a).

2.2.1 Cocoa

Cocoa trees are planted and used for production for a period of about 25 years, during which they have to be pruned regularly to keep them small. After this period they are cut down and replanted. Pruning results in about 21 kg. dry organic matter per tree per year, equivalent to about 25 tons per hectare per year (Lim, 1986a). Prunings are normally left in the field. Replacing old non-productive trees after 25 years results in about 48 kg. dry organic matter per tree or about 5,760 kg. per hectare, assuming that there are 1,200 trees per hectare (Lim, 1986b)

Besides wood, residues in the form of cocoa pods are generated and it has been estimated that about 150 kg. dry pods per ha. are left in the plantation as it provides a valuable source of potash fertiliser (Lim, 1986a).

2.2.2 Coconut

Coconut trees generate residues in the form of wood, fronds, husks and shells. About 12 to 14 fronds are shed per tree per year, yielding about 1.5 kg. dry woody biomass per frond or, assuming a density of 120 trees per ha., about 2,400 kg. per ha. (Lim, 1986a). The productive life of the tree varies between 50 and 100 years. However, no information is available on the amount of wood becoming available after replanting. Part of the wood is used as timber while another part is available as a source of energy.

With regard to husks and shells, more information is available. A handbook on coconuts (PCA, 1979) indicates that coconuts (on a wet basis) consists of husks (33-35%), shell (12-15%), copra (28-30%) and water (22-25%). The same source indicates that about 2,220 kg. of dry husks and 1,040 kg. of dry shells become available per hectare per year. However, Lim (1986a) gives figures of 5,280 kg. of dry husks and 2,510 kg. of dry shells per ha. per year. These figures refer to a large-scale estate. This clearly indicates that it is difficult to estimate the total amount of residues generated. This is also shown by the variety in crop production, which ranges from 0.5-1 ton copra per ha. or about 3-7 kg. copra per tree per year (traditional harvesting on small holdings), to 1.36-1.66 tons per ha. for plantations, and up to 3-9 tons per ha. for improved clonal varieties and intensive management.

Based on a literature survey, Bhattacharya et. al. (1993) have suggested an RPR value of 0.419 for husks with a moisture content of 10.3% (based on actual measurements) while for shells they reported an RPR value of 0.12 with a moisture content of 8.7%.

2.2.3 Oil Palm

Tree trunks and fronds become available during replanting of oil palm trees. The productive life of the trees is about 25-30 year and trees yield about 500-600 kg. stem wood and 120 kg. fronds per tree. The average density is about 142 trees per hectare but due to natural attrition at the time of replanting about 85% or 120 trees are still standing. Therefore, the average yield per ha. is about 80 tons of dry matter (Lim, 1986a,b).

Besides these, fibre, shells and empty bunches are generated during processing. Lim (1986a) reports values of 1,853 kg. of fibre, 2,780 kg. of shells and 1,483 kg. of empty bunches per hectare as dry matter.

RPR values reported by Ma et. al. (1986) range from 0.14 to 0.15 for fibres with a moisture content of 40%, 0.06-0.07 for kernel shells (moisture content 10%) and 0.23 for empty bunches with a moisture content of 50%. These values are based on direct observations in palm oil industries. Shells and fibres are normally used internally for power generation while part may be sold as fuel or used for road construction. Empty bunches are normally incinerated, after which the potash rich ash is used as fertiliser.

2.2.4 Rubber

Lim reports that rubber trees have a productive life of about 25-35 years. During replanting they yield about 180 cubic meter green wood per hectare (Lim, 1986a). This is equivalent to about 81 tons dry wood per hectare at 0.72 ton per cubic meter green wood and a moisture content of 60% (dry basis).

Rubber trees shed their leaves every year resulting in a residue resource of about 1,400 kg. per hectare. However, removal of these leaves may affect soil moisture and fertility, and may increase erosion.

2.2.5 Others

Besides the plantation crops mentioned above, there are other sources of residues in the crop plantation industry, e.g. tea (pruning every 7-10 years of tea bushes and uprooting after productive life) and coffee (prunings of shade trees and uprootings). However, very little information is available and these have therefore not been considered.

2.3 Agricultural Residues (annual crops)

Agriculture is an important part of the economy in all of the RWEDP member countries. Besides the crops it self, large quantities of residues are generated every year. Rice, wheat, sugar cane, maize (corn), soybeans and groundnuts are just a few examples of crops that generate considerable amounts of residues. These residues constitute a major part of the total annual production of biomass residues and are an important source of energy both for domestic as well as industrial purposes.

2.3.1 Rice

Rice straw: RPR values in the range of 0.416 to 3.96 have been cited in various references. The lowest among the RPR values 0.416, reported by AIT-EEC (1983) and 0.452 by Bhattacharya et. al. (1990) are based on the practice of harvesting rice in parts of Thailand and other Southeast Asian countries, where only the top portion of the rice stem along with 3-5 leaves is cut, leaving the remainder in the field. In case the rice is cut at about 2 inches above ground, the RPR becomes 1.757 (moisture content 12.71%) as reported by Bhattacharya et. al., 1993. Vimal (1979) indicates an RPR of 1.875 based on Indian experience while in Bangladesh a value of 2.858 has been reported (BEPP, 1985) which may be valid for a local variety only. For calculation purposes an RPR value of 1.757 has been used which is based on actual measurements in Thailand.

Rice husk: RPR values for rice husk range from 0.2-0.33. For calculation purposes an RPR value of 0.267 (moisture content 2.37%) has been used as reported by Bhattacharya et. al. (1993).

2.3.2 Maize

Maize stalk: The literature shows widely varying RPR values ranging from 1.0 to 4.328. Values reported by Vimal (1979), AIT-EEC (1983), Barnard et. al. (1985) and Desai (1990) are respectively 2.0, 2.3, 2.0-2.3, and 2.08 where as Massaquoi (1990) and Ryan et. al. (1991) report a value ranging from 1.0 to 2.5. For calculation purposes an RPR value of 2.0 has been assumed (moisture content 15%).

Maize cob: Bhattacharya et. al. (1993) reported an RPR of 0.273 (moisture content 7.53%) which can be assumed to be acceptable since the value was obtained from actual field measurements.

Maize husk: A value of 0.2 with an assumed moisture content 11.11%, as reported by Vimal (1979) has been used for calculation purposes.

2.3.3 Other Cereals

RPR values for wheat straw, as reported by different authors, range from 0.7-1.8. The value reported by Bhattacharya et. al. (1993), i.e. 1.75 has been used since the moisture content (moisture content 15%) has been indicated. Since reported RPR values for millet, rye, oats and barley do not show wide variations from that of wheat, the same RPR value has been used. An exception is straw from sorghum where Bhattacharya et. al. give an RPR value of 1.25 at a moisture content of 15%.

2.3.4 Cassava

Stalks: Cassava is harvested about 12 months after planting. At harvest the plants are first topped before being uprooted. Part of the stalk is retained for replanting while part is discarded. Tops (leaves) and the discarded part are sometimes left in the field and sometimes used as a domestic fuel. Out of the 10-25 tons of stems and leaves per hectare, about 8 tons becomes available as fuel or about 6 tons/ha. on a dry basis (Lim, 1986a).

When looking at RPR values, the 0.167-2.0 as reported by AIT-EEC (1983), Bhagawan (1990) and Ryan et. al. (1991) appears to be the most suitable for Asian conditions. Assuming a yield of about 30-45 tons of tubers per ha. this would result in a residue base of about 4-9 tons per hectare.

Peelings: Part of the tubers is processed into starch flour and is peeled before processing. Peels represent about 2-3% of the weight of the tuber and this would yield about 1 ton of peels (moisture content 50%) generated per ha. of cassava destined for starch production.

2.3.5 Groundnuts

Husks/shells: Barnard et. al. (1985) and Ryan et. al. (1991) recommend an RPR value of 0.5 whereas Bhattacharya et. al. (1993) give a value of 0.477 with a moisture content of 8.2%. The latter value has been used for further calculations.

Straw: Barnard et. al. (1985), Ryan et. al. (1991) and Massaquoi (1990) all give an RPR value of 2.3 for groundnut straw. Therefore, this value has been used, assuming the moisture content to be 15%.

2.3.6 Soybeans

Straw: Bhattacharya et. al. (1993) have reported an RPR value for soybean straw of 2.5 at a moisture content of 15%.

Pods: The same source as used for soybean straw indicated an RPR value for the pods of about 1.0 with a moisture content of 15%.

2.3.7 Sugar Cane

In comparison to other crops, sugar cane gives a very high dry matter yield per unit of land area. Bagasse and sugar cane tops and leaves are the main residues of which the former is normally used as an energy source for steam generation while the latter is normally used as cattle feed or is burnt in the field.

Bagasse: A number of authors including Vimal (1979), Webb (1979), and BEPP (1985) indicate an RPR value ranging from 0.1-0.33 with a moisture content of 50%. Bhattacharya et. al. (1993) give an average value of 0.29 with a similar moisture content, which has been used further for calculation purposes.

Tops/leaves: Vimal (1979) and AIT-EEC (1983) report RPR values of 0.1 and 0.125 respectively. USAID (1989) reported an RPR value of 0.3 based on actual field experiments in Thailand with a moisture content of 10%. The latter value has been used for calculation purposes.

2.3.8 Jute Stalk

BEPP (1985), Kristoferson et. al. (1991) and Ryan et. al. (1991) give an RPR value of 2.0 for jute stalks while Barnard et. al. (1985) and Desai (1990) report 1.6-2.25 and 1.37 respectively. For calculation purposes a value of 2.0 and a moisture content of 15% has been chosen.

2.3.9 Cotton Stalk

Massaquoi (1990), Kristoferson et. al. (1991) and Ryan et. al. (1991) gave similar values of 3.5 to 5.0 for the RPR. An average value of 2.755 for the range of 1.767-3.743 as suggested by Bhattacharya et. al. (1990) has been selected for calculation purposes with a moisture content of 12%.

2.4 Amount of Residues Generated

By using the data as presented in the earlier sections in addition to statistical data on forestry, cropping areas and crop production as published in national and international statistics, a calculation was made of the amount of agricultural residues generated in RWEDP member countries. Annexes 2a and 2b provide an overview of crop residues and wood residues respectively (excluding wood derived directly from trees growing in the forests, agricultural land and other land). It should be noted that a clear distinction between these two main groupings can not really be made as within the crop residues several of the residues resemble wood such as for instance cassava stalks, jute sticks and millet stalks.

In aggregate, the numbers look very attractive if not staggering. A distinction has been made between residues generated in the field and those generated during processing. The reason for this is that it may be assumed that in the latter case residues probably will be found concentrated which will make its use, for instance as a source of energy, or disposal more easy. In the former case they may be found spread over large(r) areas and may remain in the field. Examples of residues that often remain in the field are straw, stalks, tops and leaves (sugar cane). In such cases the straw and stalks are often also concentrated but generally in smaller quantities.

It should again be stressed here that large variations in RPR ratios occur and one should be very careful in applying RPR ratios across the board. Using different RPR ratio can have a tremendous influence on the amounts of residues apparently generated. For instance, one of the major world crops, rice, generates two main types of residues: rice straw and rice husks. Combined they account for about 900 million tons of residues using the suggested RPR ratio. However, using the highest ratios, the amount would increase to about 1,900 million tons while in case the lowest reported RPR ratio would be used, the amount would drop to about 300 million tons of rice straw and husks.

3. Demand for the Resources

Residues are used for many purposes and such uses often are site specific. Besides being used as **Fuel**, which can be considered as being one of the "6 F's", residues are also used as **Fodder, Fertiliser, Fibre, Feedstock** and **Further uses**. The latter "F" comprises for instance residues being used as a soil conditioner (e.g. coconut coir dust used to retain moisture in the soil, straw as a growing medium for mushroom, coconut husks as a growing medium for orchids, packing material). In some case residues may even have a multi-purpose use. Rice husk can be burned as Fuel with the ash being used by the steel industry as a source of carbon and as insulator (Feedstock, Further). Rice straw can be used as animal bedding (Fibre, Further) and subsequently as part of compost (Fertiliser), crop waste can be used as a Feedstock for biogas generation (Fuel), with the sludge being used as fertiliser.

It is sometimes assumed that residues are wastes and therefore by definition more or less 'free'. However, in practice it is unwise to assume so. In a monetized economy, even where residues are at present freely available, everything which has a use will rather sooner than later acquire a monetary value. For instance:

- About 15 years ago rice-mill owners in Indonesia gave rice husks free of charge to truck drivers and brick makers and would even provide free labour to load it. Once a market had developed, the rice-mill owners were no longer willing to do so and brick makers had to pay for the husks as well as for labour to load the husks;
- The increased use of rice husk as a boiler fuel in the Nepali carpet industry resulted in a tenfold increase in the price from 2 to 20 NRs (about 0.04 - 0.40 US$) per bag of 20 kg. over a period of only 14 months (FAO, 1992);
- In some areas in North Vietnam farmers used to burn rice straw in the field as fertiliser. However, due to an increasing shortage of fuelwood, they started using it as fuel. At the same time mushrooms growing became an important cash crop for which straw was used as growing medium. The price rose to such a level that it actually became attractive for farmers to sell the straw as the money earned was more than what they had to pay for chemical fertilisers to replace the fertilisers and trace elements found in the ash.

Even where residues have no monetary value, the wastes may be used for various purposes in the local community. Within local communities such situations are likely to be well understood but they may not be apparent for someone from outside. For example, share-cropping systems with part of the crop as well as the residues being divided between the landowner and the tiller are common. Landless people often have access to residues on common lands and sometimes may collect residues from other people's lands. Trying to use residues without offering any compensation is likely to run into problems. Even in cases where money changes hands, it may be that payments are made to someone other than the person to whom the original benefit accrued and this may lead to social disruptions in the local community.

From this it is clear that with regard to residues many factors will have to be considered. Seasonality with large quantities being available directly after the harvest, ownership and access, fraction which can be recovered economically taking into account environmental considerations, and present and competing uses are some of these factors. With regard to the present use, a brief overview will be provided here in combination with, where information is available, the amount and/or extent of its use.

3.1 Forest- and Wood Processing Residues

3.1.1 Logging residues

Logging residues consist of branches, leaves, lops, tops, damaged or unwanted stem wood. Such residues are often left in the forests for various reasons of which the low demand for fuel (with a high moisture content) in such areas is probably an important one as well as logistics. This is not to suggest that forest-residue recovery is not undertaken; For instance in Sweden there is a considerable recovery in the form of wood chips (bulk density about 300 kg/m3) for use in industries as well as domestic purposes. In Bhutan, due to the demand by the calcium carbide industry, logging residues are often converted into charcoal, which is then sold to the carbide industry.

3.1.2 Saw-milling

Sawmill residues are used for various purposes but much depends on local conditions such as demand centres nearby. Part of the residues is used by the sawmills themselves, basically for steam generation for timber drying purposes. However, the bulk remains unused (AIT, 1994). Where a local demand exists, wood residues are used for various purposes, mainly as a source of energy for brick and lime burning, other small industrial applications as well as a source of raw material such as for parquet making and blockboard. Sawdust is among others used for insect repellent making. Sawdust sometimes is briquetted and carbonised and sold as a high-grade charcoal, which commands a higher price than normal charcoal. Considerable quantities are also used to cover charcoal mound kilns.

3.1.3 Plywood production

Within the plywood industry a demand exists for residues. In Malaysia about 30-50% of the residues are used for power and steam generation while in Indonesia about 20% of the plywood mills use their own residues (AIT, 1994). The latter source indicates that in Thailand and the Philippines little of the residues is used internally by the plywood mills.

In the case of integrated wood processing factories, part of the residues is used as a raw material in blockboard and particleboard production. The same is true for sawmill residues. In Indonesia the use of the cores, e.g. for fencing, appears to be quite common, at least in the Moluccas.

3.2 Perennial Plantation Crop Residue

3.2.1 Cocoa

Cocoa tree prunings are normally left in the field as a kind of mulch while a small part may be used as domestic fuel. Cocoa pods are normally left in the field. No information is available on what is being done with wood from trees cut during re-planting. It may be assumed that a major part of this wood ends up as domestic or industrial fuel.

3.2.2 Coconut

Fronds are either left in the field (valid for large-scale plantations) or used as a domestic fuel (mainly small holder plantings). Tree trunks are both used as fuel and as timber, unfortunately with quantities unknown. However, in countries like Sri Lanka, the Philippines and other coconut growing areas, the coconut tree appears to be an important source of low-grade timber.

Husks are used as fuel for coconut processing (copra drying and small-scale coconut oil making), as a domestic fuel and as a source of fibre for rope, mats, and filling of mattresses. The shells are a good fuel and an excellent source for activated carbon production. Lim (1986a) reports that in Malaysia about 80% of the shells and 20% of the husks are used as fuel with 20% of the shells and 30% of the husks being used for other purposes. About 50% of the husks remain unused. It should be noted that in some cases, notably in Sri Lanka, a large amount of the coconuts are not processed centrally but are used for direct domestic consumption with the husks and shells used as a domestic source of energy.

3.2.3 Oil Palm

Tree trunks as well as fronds become available during replanting, with fronds also becoming available during the productive life of the tree. Fronds are normally left in the plantation as a mulching agent. As oil palm plantations are normally large scale, a considerable quantity of tree trunks are burned in the field as there is often little demand for the wood in such areas.

Shells and fibres are normally used in the palm oil mills for power generation while a small part (probably around 10%) may be sold as fuel or used for road construction. Empty bunches are normally incinerated at the mill with the potash rich ash and used as fertiliser.

3.2.4 Rubber

Wood from the rubber tree is both used as fuel and as timber. In particular in the last decade, rubber wood has become an important source of timber for the furniture industry. In South Thailand and possibly in other countries this has led to considerable competition between the brick industry and the furniture industry with prices increasing to such levels that the brick industry is looking for alternative sources of energy. In Malaysia about 62% of the rubber wood was used as fuel, 5% for other purposes while for the remaining 30-35% no information is available which could mean that such amount would be available for other purposes (Lim, 1986a).

3.3 Agricultural Residues (annual crops)

Agricultural residues constitute a major part of the total annual production of biomass residues and are an important source of energy both for domestic as well as industrial purposes. Residues are used as fuel, but a large amount is burnt in the field.

3.3.1 Rice

Rice straw: In many countries rice straw is burned in the field with the ash used as organic fertiliser. Relatively small quantities are used as animal fodder, animal bedding, raw material for paper and board making, or building material. In some countries like Bangladesh, China, Vietnam and possibly India and Nepal straw is also widely used as a domestic fuel.

Rice husk: Husks are often burnt at the ricemill just to get rid of the husks but in some countries like Thailand they are used extensively for power generation in large rice-mills. It has been estimated that in Thailand about 50-70% of the husks is used by the rice-mills. The remaining 30-50% apparently is not used although the brick industry is increasingly using it as a source of energy. In Malaysia, the Philippines and Indonesia most of the residues remain unused although also here the brick industry is becoming important as an end-user.

3.3.2 Maize, other cereals and soybeans

Very little is known about the use of residues from maize, other cereal crops and soybean straw and pods, other than that residues are widely used as a domestic fuel in particular in areas where fuelwood is scarce. In many cases the stalks and straw are left in the field or used for other purposes such as fodder, while husks, cobs and shells become available at processing sites.

3.3.3 Cassava, Jute and other wood-like residues

In the case of cassava, stalks and tops are sometimes left in the field but more often used as a domestic fuel, in particular the woody part. Cassava stalks can be used directly and the same is valid for millet stalks and pigeon pea (*arhar*) stalks. Using these residues as fuel is easy, as their size is quite small, they are easy to transport and they burn like wood. With regard to jute stalks, only the inner part is used after the jute fibres have been removed by soaking in water. This soaking requires that the jute stalks have to be dried before they can be used.

3.3.4 Cotton

Cotton stalks are often burned in the field as leaving them in the field may result in damage to future crops due to diseases, infestation, etc. Part is possibly used as a domestic fuel.

3.3.5 Groundnuts

Husks, shells and straw residues from the groundnut are used as fuel for domestic purposes but little if any is known about amounts. Part of the groundnuts are sold in the shell and such shells are normally no longer available as fuel.

3.3.6 Sugar Cane

Bagasse and sugar cane tops and leaves are the main residues of which the former is normally used as an energy source for steam generation while the latter is normally used as cattle feed or is burnt in the field. Most sugar factories burn all the bagasse they generate, even at very low efficiencies. This is done to ensure that all bagasse is burned, as dry bagasse is known to be a fire hazard. In some countries bagasse is also used as a raw material for the paper and board industry.

Increasing the combustion efficiency in the sugar industry could result in the saving of considerable quantities of bagasse which either could be sold to paper factories or used to generate power and heat (co-generation).

3.4 Amount of Residues Used

Little is known about the amounts of residues used for various purposes, with the exception of the sugar industry. This lack of knowledge is due to the scattered nature of the residue generation, its seasonality and differences in local situations. This applies to the production and use of residues as fuel and for competing uses, which have an influence on the availability, and price of residues. Besides these factors, there are other factors which play a role but for which even less is known, for example availability of equipment, environmental conditions.

By using the data of Annex 2a and information on the consumption of crop residues, as is available from various sources, a very rough overview can be made of the supply/demand situation in the 16 RWEDP member countries. This is shown in the figure in Annex 3. This exercise is interesting in setting a general perspective in that it shows that in most countries there still is a considerable amount of residues, which apparently are not used. However, it should be emphasised that both data on consumption and production of residues are incomplete, so no firm conclusion can be drawn. For some countries no information is available with regard to consumption, resulting in high amounts of residues still available. For the other countries it may be assumed that the consumption data underestimates the actual use, also resulting in overestimating the amount of residues still available.

Furthermore, it should be noted that consumption refers only to fuel use, not including non-energy use of the residues. Residues play an important role in soil fertility and a total removal of all above ground residues could lead to soil degradation. However, the issue of soil fertility and recycling of residues is not well understood. Returning residues to the soil by ploughing may play a role in maintaining the quality of the soil by keeping up its organic content. It is also possible that the burning of residues in the fields plays an important role in supplying trace elements. While burning the residues in the field is simple and easy to do, ploughing uncomposted residues into the soil is not easy.

As is the case with residue generation and use, it is also clear that no generalisation can be made of the effect that increased use of residues will have on soil condition. The importance of any of these factors will depend largely upon specific local conditions. The problem is compounded by the fact that there is likely to be very little local knowledge about what impact a sudden change in residue recycling patterns would have on the soil. In principle, monitoring of agricultural yields after the change should indicate whether any adverse effects have taken place. R&D of this type, however, would be extremely time consuming, complex and expensive while changes which may occur would be difficult to detect as over time agricultural practices may change which in turn would affect the situation.

4. Concluding Remarks

The previous chapters have shown that considerable quantities of residues remain unused. However, this statement is based on data that can be considered far from satisfactory and incomplete. Much more information will have to be gathered on the use and availability of residues. Furthermore, as has been said before and is emphasised here again, an enormous diversity exists not only between countries but often even between sub-national areas. Any conclusion which could possibly be drawn from the above for a given country or area may therefore have little relevance to other areas. Therefore, one could question the usefulness of having a database system on residue generation and utilisation at a national level. Considering the fact that so many variables influence the result of the database, a system on a sub-national or possibly even on a smaller geographical area may be required.

It should also be noted that, when collecting data and making calculations, one should be cautious not to loose sight of the implications on social aspects, e.g. the use of residues as a domestic fuel, farmers who produce residues as a by-product.

Very little, if any, information is available on how the farmers themselves see their situation and the trade-offs they make willingly or unwillingly with regard to residue generation and use. Studies should be carried out to determine the possible effects of an increased use of residues at the farm level, for example on soil conservation and degradation (and effect on crop growth), income generation, on the local environment (e.g. increased use of other sources of energy), and the effect on local communities (e.g. access to residues).

Promoting the use of residues for other applications such as power generation will not only put a value on the residues but may also deprive a part of the population (often the poorest section) of their cooking and heating fuel. These factors should be considered when deciding upon a strategy for increased use of residues.

5. Bibliography

Adams, M. (1995), *Technical Report: Forest Products, Harvesting and Utilization Component*, Paper presented to a Project Formulation Workshop on Sustainable Conservation, Management and Utilization of Tropical Rainforests in Asia, GCP/RAS/148/AUL, Bangkok, 6-8 February 1995.

AIT (1994), *Business Opportunities for Power Generation from Biomass Residues in ASEAN*, Vol. 1-3. EC-ASEAN COGEN Programme, AIT, Bangkok.

AIT-EEC (1983), *Evaluation and Selection of Ligno-Cellulose Wastes which can be converted into Substitute Fuels*, Project report submitted to EEC, Belgium.

Barnard, G. and Kristoferson, L. (1985), *Agricultural residues as fuel in the third world*, Earthscan - The Beijer Institute, Energy Information Programme, Earthscan.

BEPP (1985), *Bangladesh Energy Planning Project: Draft Final Report*, Rural Energy and Biomass Supply, Vol. IV.

Bhattacharya, S.C. and Shrestha, R.M. (1990), *Biocoal Technology and Economics*, RERIC, Bangkok, Thailand.

Bhattacharya, S.C., Pham, H.L., Shrestha, R.M. and Vu, Q.V. (1993), *CO_2 emissions due to fossil and traditional fuels, residues and wastes in Asia*, AIT Workshop on Global Warming Issues in Asia, 8-10 September 1992, AIT, Bangkok, Thailand.

Bhushan, B. (1977), *Agricultural Residues and their Utilization in some Countries of South and South-East Asia*, in: 'Residue Utilization: Management of Agricultural and Agro-industrial Residues', FAO/UNEP, Vol. 1.

Desai, A.V. (1990), *Patterns of Energy Use in Developing Countries*, UNU, Tokyo, Japan.

FAO (1982), *Agricultural Residues: Bibliography 1975-1981*.

FAO (1990), *Energy conservation in the mechanical forest industries*, FAO Forestry paper No. 93, FAO-Rome, 1990.

FAO (1992), *Wood/Biomass based Energy Systems in Rural Industries and Village Applications, Nepal*, Report of the National Seminar held in Kathmandu, 29-31 July 1992. FAO-RWEDP.

FAO (1998), *Proceedings of the Regional Expert Consultation on Modern Applications of Biomass Energy*, FAO Regional Wood Energy Development Programme in Asia, Report No. 36, Bangkok.

FRIM (1992), *Utilization of Industrial Wood Residues*, Paper presented at the workshop on "Logging and Industrial Wood Residues Utilization" in Jakarta, Indonesia, 24 August 1992.

GOI (1990), *Situation and Outlook of the Forestry Sector in Indonesia*, Ministry of Forestry, Government of Indonesia in cooperation with FAO, Rome.

Ishaque, M. and Chahal, D.S. (1991), *Crop Residues*, In: 'Food, Feed and Fuel from Biomass', Edited by D.S. Chahal, pp. 15.

Jalaluddin, Harun. Abdul Rahman Md. Derus and W.C. Wong (1984), *Wood residue and its utilization in Peninsular Malaysia*, Proceedings of the seminar on "Management and Utilization of Industrial Wastes". Universiti Pertanian Malaysia, 13-14 Sept. 1984.

Kristoferson, L.A. and Bokalders V. (1991), *Renewable Energy Technologies: Their Application in Developing Countries*, IT Publications, London.

Lim, K.O. (1986a), *The energy potential and current utilization of agriculture and logging wastes in Malaysia*, Renewable Energy Review Journal, Vol. 8, No. 2, December 1986, RERIC-AIT, Bangkok.

Lim, K.O. (1986b), *The future energy potential of replanting wastes in Malaysia*, Renewable Energy Review Journal, Vol. 8, No. 2, December 1986, RERIC-AIT, Bangkok

Ma, A.N. and Ong, A.S.H. (1986), *Biomass Energy from the Palm Oil Industry*, in: ASEAN Conference on Energy from Biomass, 13-15 October, Penang, Malaysia.

Mahajan, K.C. and Mishra, J. (1992), *Energy from Paddy Husk - An Overview,* In: Energy management, Oct. Dec. 1992, pp. 5-14.

Massaquoi, J.G.M. (1990), *Agricultural residues as Energy Source*, In: ‘Energy for Rural Development’, Edited by Bhagvan, M.R. and Karekezi, S.

PCA (1979), *Technical data handbook on the coconut, its products and by-products*, Philippine Coconut Authority, Casein City, Philippines, 1979.

Ryan, P. and Openshaw, K. (1991), *Assessment of Biomass Energy Resources: A Discussion on it's Needs and Methodology*, World Bank.

Smill, V. (1983), *Biomass Energies, Resources, Links and Constraints*.

Strehler, A. and Stutzle, W. (1987), *Biomass Residues*, In: ‘Biomass Regenerable Energy’, Edited by Hall, D.O. and Overend, R.P.

USAID (1989), *Baling Sugarcane Tops and Leaves: The Thai Experience*.

Vimal, O.P. (1979), *Residue Utilization, Management of Agricultural and Agroindustrial Residues of Selected Tropical Crops (Indian experience)*, Proceedings of UNEP/ESCAP/FAO Workshop on Agricultural and Agroindustrial Residue Utilization in Asia and Pacific Region.

Vimal, O.P. and Tyagi, P.D. (1984), *Energy from Biomass, An Indian Experience*.

Webb, B. (1979), *Technical Aspects of Agricultural and Agroindustrial Residues Utilization*, Proceedings of UNEP/ESCAP/FAO Workshop on Agricultural and Agroindustrial Residue Utilization in Asia and Pacific Region.

WETT (1997), *The Role of Wood Energy in Europe and OECD*, Forestry Department, FAO, Rome

Weingart, J.M., Jezek, P.A. and Morris G., (1988), *A pre-feasibility assessment of the potential of wood waste power systems for the Indonesian wood products industry*, USAID-BEST Project, In: ‘Forest Resources and Wood Based Biomass Energy as Rural Development Assets’, 1994. William R. Bentley and Marcia M. Gowen, Eds.

Annex 1: Estimates of Residue to Product Ratio[1]

Crop and Reference	RPR	Moisture content in %	C %	N %	LHV MJ/Kg.	Ash %
RICE STRAW						
Webb '79	2.60 - 3.96	10-12				12.7-21.4
Vimal '79	1.88					
AIT-EEC '83	0.42	27			15.10	16.98
BEPP '85	2.86					
Barnard ea. '85	1.40 - 2.90					
Strehler '87	1.40	12-22	41.44	0.67	10.9	17.4
Bhattacharya '90	0.452	12.71	24.79		16.02	21.05
Massaquoi '90	1.10 - 3.00					
Ishaque '91	1.40					
Ryan ea '91	1.10 - 2.90					18-19
Kristoferson ea '91	1.10 - 2.90					
Bhattacharya ea '93	1.757	12.71	39.84		16.02	
RICE HUSK						
Bhushan '77	0.20 - 0.25				12.69	18-19
Webb '79	0.20 - 0.25	10.5			13.97	16
FAO '82	0.35	7.26				24.75
AIT-EEC '83	0.30	14			14.39	21.14
Vimal '84		9.6	38.5		14.39	21.14
BEPP '85	0.321					
Bhattacharya ea ' 93	0.267	12.37			19.33	0.70
Ryan ea '91	0.30					15-20
Mahajan '92	0.20	8.92	38.10	1.50	13.59	17.34
MAIZE STALK						
Webb '79	3.20 - 4.33					
Vimal '79	2.00					
AIT-EEC '83	2.30					
Vimal '84		11.5			19.66	14.20
Barnard ea '85	2.00 - 2.30					
Strehler '87	1.00	22	47.09	0.81	5.25	5.77
Massaquoi '90	1.00 - 2.50					
Desai '90	2.08					
Ryan ea '91	1.00 - 2.50	Air dry				

[1] Notes: RPR = Residue-to-Product-Ratio; C % = Carbon content on weight basis; N % = Nitrogen content on weight basis; LHV = Lower heating value (energy content); Moisture and ash content given on weight basis

MAIZE COB						
Bhushan '77	0.30					
Webb '79	0.86	7.00				2.40
Vimal '79	0.30					
Vimal '84		8.60			14.64	13.80
Barnard ea '85	0.20 - 0.50					
Massaquoi '90	0.20 - 0.50					
Ryan ea '91	0.70 -1.80					
Bhattacharya ea '93	0.273	7.53	43.14		16.28	
AIT-EEC '83	0.20					
MAIZE HUSKS						
Bhushan '77	0.30					
Webb '79	1.00 (h+s)					
Vimal '79		11.11				1.15
Ryan ea '91	0.20					
Massaquoi '90	0.20					
WHEAT STRAW						
Vimal '84		9.20	38.4	0.30	15.90	18.00
BEPP '85	1.50					
Barnard ea '85	1.00 - 1.66					
Strehler '87		12-22	47.31	1.36	13.90	7.57
Massaquoi '90	0.70 - 1.80					
Desai '90	1.48					
Ishaque ' 91	1.70					
Kristoferson ea '91	1.00 -1.80					
Ryan ea '91	0.70 -1.80					
Bhattacharya ea '93	1.75	15	42.55		12.38	
MILLET / RYE / OATS STRAW						
Smill '83	1.50					
Barnard ea '85	1.10-1.95					
Ishaque '91	1.10					
Kristoferson ea '91	1.80-2.00					
Ryan ea '91	1.10 - 2.00					
Bhattacharya ea '93	1.75	15	42.55		12.39	

BARLEY STRAW						
Barnard ea '85	0.60 - 1.75					
Strehler ' 87		12-22	45.67	0.43	12.95	4.30
Massaquoi '90	0.60 - 1.80					
Desai '90	1.58					
Ishaque '91	1.70					
Kristoferson ea '91	1.50 - 1.80					
Ryan ea '91	0.60 - 1.80					
Bhattacharya ea '93	1.75	15	42.55		12.38	
SORGHUM STRAW						
Smill '83	1.20					
Barnard ea '85	1.80 - 7.40					
Massaquoi '90	0.90 - 4.60					
Desai '90	2.26					
Ishaque '91	1.00					
Kristoferson ea '91	0.90 - 4.90					
Ryan '91	0.90 - 4.60					
Bhattacharya ea '93	1.25	15	42.55		12.38	
CASSAVA STALKS						
Webb '79	1.00					
AIT-EEC '83	0.1617					
Smill '83	0.20					
Massaquoi '90	0.20					
Ryan ea '91	0.20					
Bhattacharya ea '93	0.062	15	44.14		17.50	
GROUNDNUT HUSKS/SHELLS						
Barnard ea '85	0.50					
Massaquoi '90	1.20					
Ryan ea '91	0.50					
Vimal '84		7.30	45.92	1.09		
Bhattacharya ea '93	0.477	8.2	41.69		15.66	

GROUNDNUT STRAW						
Vimal '84		12.1			17.58	1.30
Barnard ea '85	2.26					
Massaquoi '90	2.30 - 2.90					
Ryan ea '91	2.20 - 2.90					
Kristoferson ea '01	2.30					
SOYABEAN STRAW						
Smill '83	1.00 (pods ?)					
Bhattacharya ea '93	2.50 + 1.00 (pods)	15	42.55		12.38	
AIT-EEC '83	3.94					
SUGAR CANE BAGASSE						
Vimal '79	0.33	48.0			9.22	2.0
Webb '79	0.289	52.0			9.29	3.2
AIT-EEC '83	0.141	50				
Strehler '87	1,16	40 - 60	46.95	0.30	7.75	3.90
Bhattacharya ea '93	0.29	49	43.3		18.10	
Ryan ea '91	0.1 - 0.3					10-12
SUGAR CANE TOPS / LEAVES						
Vimal '79	0.1	75.0				
AIT-EEC '83	0.125	50			17.41	1.2
USAID '89	0.30				15.81	
JUTE STALK						
BEPP '85	2.0					
Barnard ea '85	1.60 - 2.25					
Desai '90	1.37					
Ryan ea '91	2.00					
COTTON STALK						
Vimal '84		12.0			13.81	13.5
Barnard ea '85	3.52					
Massaquoi '90	3.50 - 4.00					
Kristoferson ea '91	3.50 - 5.00					
Bhattacharya ea '90	1.77 - 3.74	12	18.88		18.61	5.26
Ryan ea '91	3.50 - 4.00					
Pigeon Pea						
Ryan ea '91	5.00					

Cow Pea					
Ryan ea '91	2.90				
Barnard ea '85	2.90				
Coconut Husk					
Bhushan '77	0.50 - 0.55				
Bhattacharya ea '93	0.419	10.3	47.34	18.62	
Ryan ea '91	1.60				6.0
Coconut Shell					
Webb '79	0.438	13.0		16.78	
Barnard ea '85	0.70 - 1.10				
Ryan ea '91	0.65				1.0
Bhattacharya ea '93	0.12	8.7	46.7	18.09	
Oil Palm Shell					
Bhushan '77	0.06 - 0.09	6	20		4
Webb '79	0.047	6		8.2	
Ma & Ong '86	0.06 - 0.07	10		18.83	
Oil Palm Fibre					
Bhushan '77	0.11 - 0.15	30-40			
Webb '79	0.122	30/10		6.33/16.53	5.0
Ma & Ong '85	0.11 - 0.15	40		11.34	
Oil Palm Empty Bunches					
Bhushan '77	0.25 - 0.27	29.6 (dry)			5.0
Webb '79	0.24	60		2.34	5.0
Ma & Ong '85	0.23	50		8.16	
Coffee Husks					
Bhattacharya ea '93	21	15	42.55	12.38	

Annex 2a: Estimated Amount of Crop Residues Generated in Asia (1997)

Unit: 1,000 ton

FIELD BASED RESIDUES																			
Crop	*Residue*	*RPR*	*BGD*	*BHU*	*CAM*	*CPR*	*IND*	*INS*	*LAO*	*MAL*	*MLD*	*MYA*	*NEP*	*PAK*	*PHI*	*SRL*	*THA*	*VIE*	*RWEDP*
Rice	Straw	1.757	49,517	88	6,000	356,146	220,087	86,539	2,917	3,461	-	31,052	6,397	11,502	19,800	3,935	39,412	48,574	885,426
Wheat	Straw	1.750	2,545	9	-	215,758	121,231	-	-	-	-	152	1,876	29,138	-	-	1	-	370,710
Millet	Stalks	1.750	102	12	-	4,376	18,375	-	-	-	0	262	499	370	-	7	-	-	24,004
Maize	Stalks	2.000	3	78	129	209,411	19,600	18,649	160	96	-	572	2,735	2,502	8,665	66	7,684	3,281	273,631
Cassava	Stalks	0.062	-	-	4	223	371	934	4	25	0	5	-	-	121	16	1,121	123	2,948
Cotton	Stalks	2.755	207	-	1	38,044	20,519	72	63	-	-	463	-	13,210	15	-	207	39	72,839
Soybeans	Straw+pods	3.500	-	5	99	51,583	18,725	4,751	12	0	-	219	50	26	32	3	1,282	359	77,144
Jute	Stalks	3.000	2,649	1	3	630	4,500	-	-	-	-	118	42	0	-	-	30	67	8,040
Tobacco	Stalks, etc.	2.000	76	0	20	7,862	1,247	280	36	23	-	95	9	183	130	20	149	57	10,187
Sugar cane	Tops	0.300	2,256	4	51	24,770	83,175	8,329	24	480	-	1,237	489	12,600	8,100	415	13,755	3,428	159,113
Cocoa	Pods	1.000	-	-	-	-	6	296	-	120	-	-	-	-	8	4	0	-	434
Total Field Based			*57,355*	*197*	*6,307*	*908,803*	*507,837*	*119,851*	*3,216*	*4,206*	*0*	*34,175*	*12,097*	*69,531*	*36,870*	*4,464*	*63,642*	*55,927*	*1,884,477*
PROCESS BASED RESIDUES																			
Crop	*Residue*	*RPR*	*BGD*	*BHU*	*CAM*	*CPR*	*IND*	*INS*	*LAO*	*MAL*	*MLD*	*MYA*	*NEP*	*PAK*	*PHI*	*SRL*	*THA*	*VIE*	*RWEDP*
Rice	Husk	0.267	7,525	13	912	54,121	33,445	13,151	443	526	-	4,719	972	1,748	3,009	598	5,989	7,381	134,553
Maize	Cob	0.273	0	11	18	28,585	2,675	2,546	22	13	-	78	373	342	1,183	9	1,049	448	37,351
Maize	Husks	0.200	0	8	13	20,941	1,960	1,865	16	10	-	57	273	250	866	7	768	328	27,363
Coconut	Shells	0.120	11	-	6	14	1,176	1,765	-	116	2	25	-	0	1,446	228	170	168	5,128
Coconut	Husks	0.419	37	-	22	49	4,106	6,163	-	405	5	88	-	1	5,050	796	595	587	17,905
Groundnut	Husks	0.477	19	-	3	4,640	3,816	467	5	2	-	267	-	56	18	2	70	168	9,536
Groundnut	Straw	2.300	91	-	16	22,374	18,400	2,254	26	12	-	1,286	-	271	85	12	339	812	45,978
Oil Palm	Fibre	0.140	-	-	-	85	-	3,752	-	6,118	-	-	-	-	33	-	322	-	10,310
Oil Palm	Shell	0.065	-	-	-	40	-	1,742	-	2,841	-	-	-	-	15	-	150	-	4,787
Oil Palm	Bunches	0.230	-	-	-	140	-	6,164	-	10,051	-	-	-	-	55	-	529	-	16,938
Sugar cane	Bagasse	0.290	2,181	4	50	23,944	80,403	8,051	23	464	-	1,196	472	12,180	7,830	401	13,297	3,314	153,809
Coffee	Husk	2.100	-	-	1	101	431	1,011	23	21	-	4	-	-	254	24	159	841	2,868
Total Process Based			*9,864*	*36*	*1,040*	*155,034*	*146,932*	*48,932*	*559*	*20,578*	*7*	*7,720*	*2,091*	*14,848*	*19,844*	*2,076*	*23,438*	*14,047*	*466,527*
TOTAL			67,220	232	7,348	1,063,837	654,249	168,782	3,776	24,784	7	41,894	14,188	84,379	56,715	6,541	87,079	69,974	2,351,003

Estimates based on crop production and RPR values (see section 2.2 and 2.3). Data for crop production available from FAO Statistics (see http://www.fao.org).

Annex 2b: Estimated Amount of Wood Residues Generated in Asia (1997)

Forestry-Based Wood Residues (1,000 ton)

Process	Residue Type	Rate (%)	BGD	BHU	CMB	CPR	IND	INS	LAO	MAL	MLD	MYA	NEP	PAK	PHI	SRL	THA	VIE	RWEDP
Logging	Solid	40	253	21	485	46,753	11,098	16,659	366	16,325	-	1,411	289	962	1,426	296	1,315	2,094	99,754
Saw-milling	Solid	38	33	9	83	12,612	8,294	3,485	147	3,981	-	167	295	608	149	2	154	342	30,362
	Sawdust	12	11	3	26	3,983	2,619	1,101	47	1,257	-	53	93	192	47	1	49	108	9,588
Plywood	Solid	45	1	3	17	4,651	143	5,601	5	2,399	-	14	-	18	297	4	104	22	13,278
	Dust	5	0	0	2	517	16	622	1	267	-	2	-	2	33	0	12	2	1,475
Particle board	Dust	10	1	1	-	709	10	53	0	92	-	-	-	8	1	0	33	0	909
Chemical pulp	Black liquor		0.1	-	-	11	2	19	-	1.3	-	-	-	-	0.6	0.1	-	-	34
Field Based Residues			253	21	485	46,753	11,098	16,659	366	16,325	-	1,411	289	962	1,426	296	1,315	2,094	99,754
Processing Based – Solid Wood			34	11	100	17,263	8,437	9,087	152	6,380	-	181	295	626	446	7	258	364	43,640
Processing Based – Fines Dust			11	4	28	5,209	2,645	1,776	47	1,616	-	54	93	202	81	1	93	111	11,972
Processing Based – Liquids			0.1	-	-	11	2	19	-	1.3	-	-	-	-	0.6	0.1	-	-	34
Total Wood Residues			299	36	614	69,235	22,182	27,541	566	24,322	-	1,646	677	1,790	1,953	305	1,667	2,569	155,400

Estimates based on wood production and rate of residue generation (see section 2.1). Data for wood production available from FAO Statistics (see http://www.fao.org). For black liquor, it was assumed that 1 ton of chemical pulp produced, produces 1 m^3 of black liquor in wood equivalent.

Agro-Based Wood Residues (1,000 ton)

Process	Residue Type	Annual Yield (ton/ha)	BGD	BHU	CMB	CPR	IND	INS	LAO	MAL	MLD	MYA	NEP	PAK	PHI	SRL	THA	VIE	RWEDP
Cocoa tree	Prunings	25.20	-	-	-	-	17	898	-	454	-	-	-	-	38	13	2	-	1,422
Coconut tree	Fronds	2.34	218	-	129	285	23,888	35,856	-	2,357	32	510	-	5	29,379	4,631	3,461	3,413	104,163
Rubber tree (25 yr.)	Solid	2.59	-	-	174	1,852	2,211	6,360	-	4,382	-	117	-	-	797	429	7,852	732	24,906
Palm oil tree (30 yr.)	Solid	2.20	-	-	-	371	-	16,332	-	26,632	-	-	-	-	144	-	1,402	-	44,881
Palm oil tree (30 yr.)	Fronds	0.48	-	-	-	81	-	3,563	-	5,811	-	-	-	-	32	-	306	-	9,792
Cocoa tree (25 yr.)	Solid	2.30	-	-	-	-	17	898	-	454	-	-	-	-	38	13	2	-	1,422

Estimates based on area of production and rate of residue generation (see section 2.2). Data for area of production available from FAO Statistics (see http://www.fao.org). For rubber, palm oil and cocoa, waste is available from replanting. Figures in brackets indicate rotation period. For calculations, it is assumed that replanting occurs on an average annual basis.

Annex 3: Production and Consumption of Crop Residues (1995)

The figure below gives an overview of total estimated production and consumption of crop residues for all 16 member countries. This shows that production greatly exceeds consumption. However, it should be emphasised that both data on consumption and production of residues are incomplete, so no firm conclusion can be drawn. Further more, consumption data refer to energy purposes only, excluding other end uses for the residues, such as building material, fodder and fertiliser.