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Technical Aspects and Problems of Wood Combustion and Consumption Accounts in Brazil

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The physical properties and combustion characteristics of wood are poor compared to the fossil fuels, particularly the liquid and gaseous forms. Wood is a bulky solid so transportation costs are high. Green wood is wet so it burns poorly and should be stored to dry. In wet climates it may rot before it dries. Since wood is a solid it is difficult to control combustion, hence efficiency is usually low. Moisture content, hence combustion properties vary considerably between species. However, the premium fuels are not readily available in many countries or regions, so wood remains an important energy option in spite of these disadvantages.

Measuring wood use -

Volume units: At the point of use in a household or in the more informal commerce of firewood the standard unit is the loosely stacked cubic meter. This is technically called a stère and abbreviated m^3 (st) or (st). Unfortunately it is often called a cubic meter and confusion arises with the more precisely defined solid cubic meter m^3 which is just that, a solid cubic meter of wood such as one might cut out of a giant tree. The relation between stères (st) and solid cubic meters is not simple since it depends on the size and type of wood. Table I-A shows that the conversion factor varies from .8 to .2 depending on the type of wood.

MEB-70* chooses .7 for the conversion factor for Brazilian records. This may be too high. A factor of .65 is used in the FAO literature. One commonly hears in small towns that meters are 90 cm long, also, wood is sold off the truck rather than being sold after being neatly piled on the ground. Furthermore, only about 20% of firewood comes from plantations yielding wood that stacks in a compact fashion.

Since Brazilian firewood consumption is calculated from estimates of unit consumption beginning with stères, it may be that there is approximately a 10% error in the direction to over report the total consumption in solid m^3.

For other derivatives of wood, measurements are made in m^3 or in tons but there generally are different conversion factors for each derivative. The Round Wood equivalent m^3 RWE or in Portuguese "Equivalência em Madeira Roliça" in m^3 is given in Table I-B for a variety of products. Note that generally $2m^3$ (solid) of round wood produces $1m^3$ of wood materials whereas generally $5m^3$ of round wood produces 1 ton of cellulose or paper products.

* Matriz Energetica Brasileira - 1970

Table I-A

Reducing factors for converting stacked wood to solid wood content

Species	Diameter class of material	Reducing factor
Conifer	Large round and straight	0·80
	Medium split billets smooth and straight	0·75
	Medium split billets crooked	0·70
	Small round firewood	0·70
Hardwood	Large split billets smooth and straight	0·70
	Large split billets crooked	0·65
	Small round firewood smooth and straight	0·65
	Small round firewood crooked	0·55
Small branches and twigs	Small round firewood crooked	0·30–0·45
Brushwood	Small round firewood crooked	0·15–0·20

Source: Troup (1926) as presented by D.E. Earl (ref. 14)

Table I-B

Conversion Factors for Forest Products
in Terms of Round Wood Equivalents (RWE)

Products	Unit	Solid m^3 (RWE)	
Fiber Panels	m^3	1.93	(1)
pressed	m^3	2.7	
unpressed	m^3	.5	
Particle Panels	m^3	1.8	
Composite and Laminated	m^3	2.4	
Cellulose			
short fiber	t	4.2	
long fiber	t	5.2	
Paper	t	5.1	(1)
Firewood	m^3 (st)	.2 - .8	
Lumber	m^3	1.9	(2)
Charcoal	mdc (3)	1.5 - 2.0	(4)

(1) an average value
(2) conifers average 1.8, non-conifers average 2.0
(3) cubic meter of charcoal - not pressed, hence variable
(4) Eucalyptus plantations can produce 1 mdc with only 1.5 m^3 whereas 2.0m^3 from the Savannahs are necessary

Source: R.F. Castro and J.R. Nascimento IBDF/COPLAN (ref. 16)

Density:

Different species of wood have quite different densities but the average values don't seem to vary very much from one country to another. Some types of Eucalyptus are quite dense but although the trend is toward increasing use of this species in Brazil it still provides only a small fraction of total firewood.

Table I-C shows the values of density used by MEB-70 and BEN-78* and those of a North American reference.

Table I-C Densities

Firewood	Source	Comments
400 ± 20% kg/m^3	MEB-Normas Tecnicas 1972 used by MEB-FINEP** BEN-78 etc.	Apparently this is dry weight for solid m^3
320 ± 10% kg/m^3	Tillman (13)	Dry weight, loose-packed North American woods
500 ± 10% kg/m^3	Tillman	Dry weight, solid m^3 North American woods
Charcoal		
240 ± 5% kg/m^3	MEB-Normas Tecnicas 1972 used by MEB-FINEP BEN-78 etc. Tillman	Dry weight/loose-packed

The Brazilian value of 400 kg/m^3 seems low for a dry weight value and clearly too low for a wet weight value. This will be examined in section on calculating energy equivalents of wood.

* Balanço Energetico Nacional - 1978
Ministry of Mines and Energy

** Updating of MEB-70 done by FINEP November 1979

Heating Value of Wood Fuels:

This topic has been reviewed by Tillman (13) and that work was an important source for this discussion. The heating value of wood depends on the species but the most important variable is the moisture content which varies considerably between species but also depends on the conditions which prevail between the time the wood is cut and when it is burned. It is common but wrong to believe that the energy necessary to evaporate water and some interference of water with the completion of combustion are the principal reasons why wet wood is a less useful fuel than dry wood. It is simply the dilution of the fuel with a heavy, relatively inert substance that is most important in diminishing the heating value of wood. This becomes evident in the relationships shown in Figures I-A and I-B. Another condition, however, is that wet wood is hard to ignite, requiring greater efforts, skill and time on the part of the user.

(13) D.A. Tillman, Wood as an Energy Resource, Academic Press 1978, New York & London

The heats of combustion of different wood species average in the range from 4.5 to 5 kcal/g for oven-dry 5-8% or 0% moisture measurements. Figure I-A uses 5 kcal/g (which equals 5 Mkcal/Ton). If the Brazilian average is 4.5 kcal/g, Figure I-A is still very close to representing the decline of this value with increasing moisture content. In Figure I-A the top line shows the simple effect of dilution by water. For example, if 1 kg of sample is actually 50% water then obviously only 50% as much heat could be obtained from that kg of material as from 1 kg of wood without water. The middle line shows principally the result of energy lost to removing water by evaporation.

The equation (of theoretical origin) for the middle line of Figure I-A is:

$$HV_m = HV_o \left[1 - 1.14M\right]$$

The constant	1.14	=	1.00	+	0.11	+	0.03
The terms are due to:			water dilution of fuel		heat lost to evaporate water		unknown

This equation was presented by Tillman but only the first two effects were identified. There is excellent statistical agreement between this formula and a collection of experimental measurements.

Figure I-B shows how the heat availability declines for a given amount of wood (dry weight basis) in the presence of different amounts of water. From this point of view the effect of water seems very modest. The problems which moisture presents are better represented in Figure I-A.

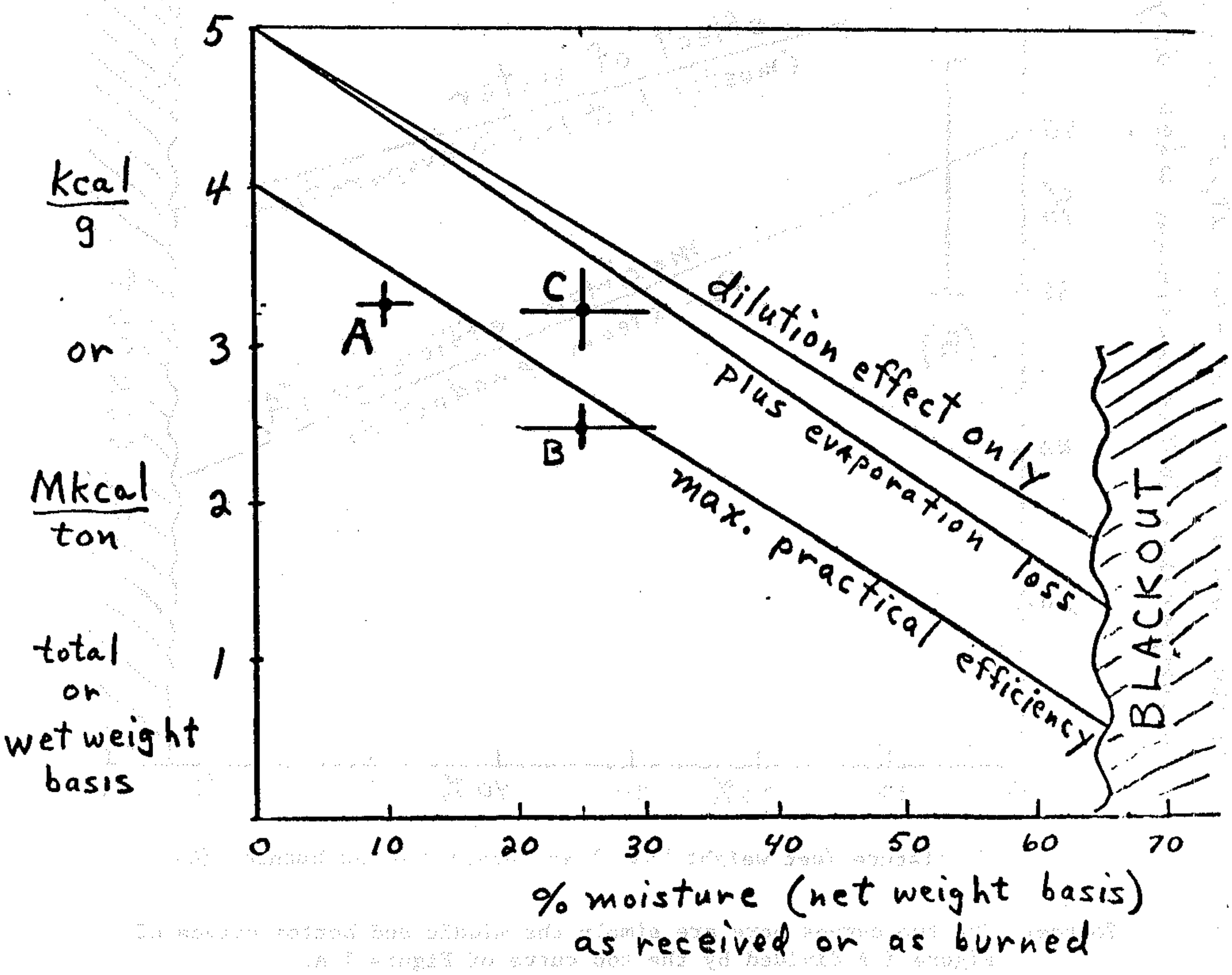
The lowest line on Figure I-A shows the maximum yield from wood combustion assuming steam production with the highest practical efficiency again as a function of moisture content. In Figure I-B this same line is shown along with a vertical line which shows the range of steam production for standard commercial steam boilers. One sees that wood efficiencies are comparable to those for oil for wood with moisture content below 30%. The gigantic oil-fired boilers of large electric generating plants can reach 90% efficiency in steam production.

Comparison to Wood Heating Values Used in Brazil

On Figure I-A, crosses A and B represent the values given regularly in government publications. For example, BEN-78 uses 2.52 Mkcal/Ton to calculate the energy equivalence of the firewood usage calculated by updating MEB-70. Referring to Figure I-A we can see that the values A and B seem clearly to represent practical values rather than the calorimetric values represented by the middle or top lines. The convention for comparisons made in TEP should be in terms of calorimetric values. For example, 10.8 Mkcal/Ton is used for petroleum, not some fraction of it representing some practical average such as the 60 to 90% shown for steam production by oil on Figure I-B.

Figure I-A

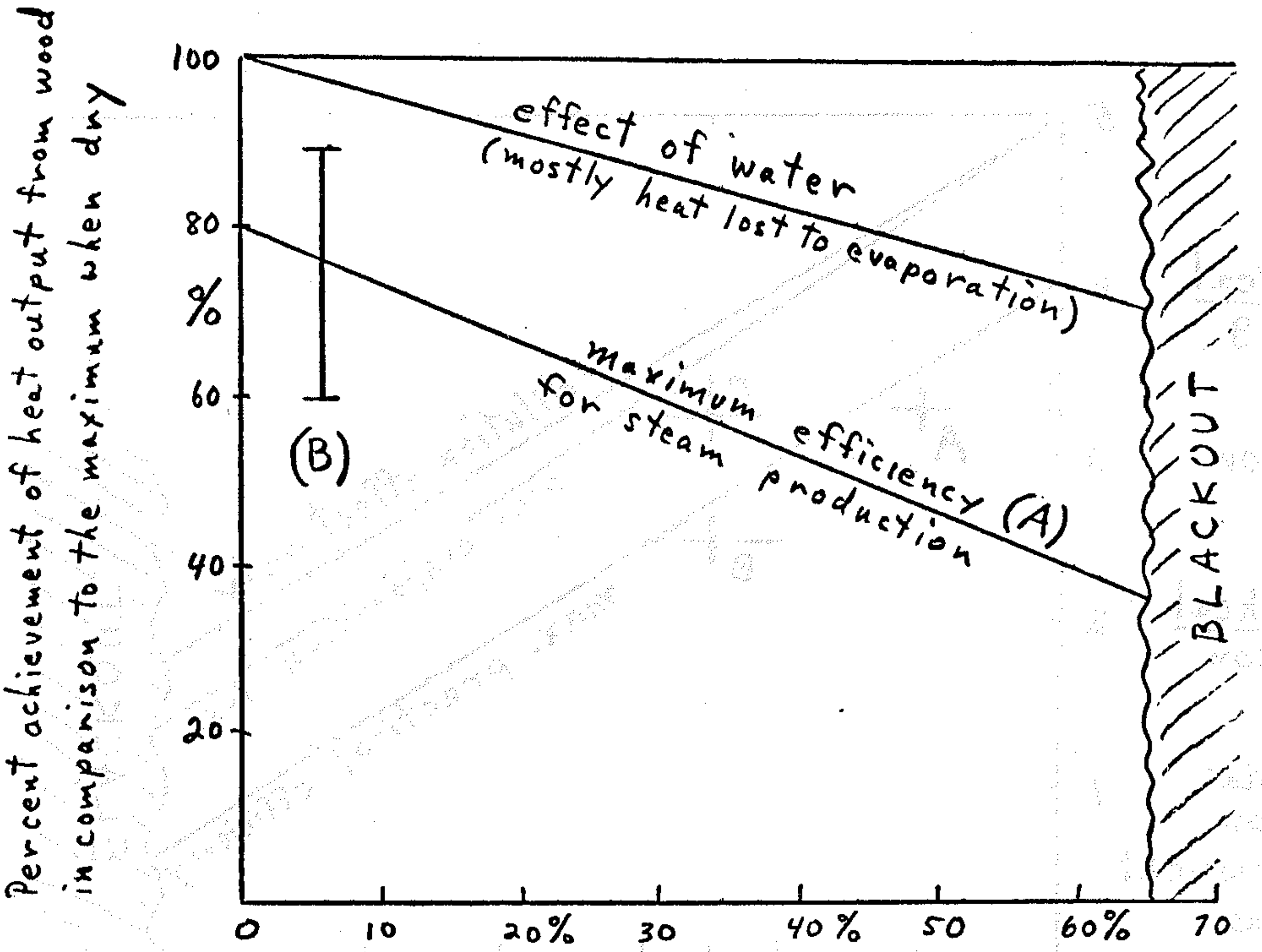
Dependence of Heating Value with Moisture Content. Tillman (13)



(Mkcal/Ton)	Moisture	Source
A. 3.25 ± 5%	10%	Belgo Mineira
B. 2.52 ± 5%	20-30%	currently accepted National value
C. 3.2 ± 10%	20-30%	proposed in this paper

Figure I-B

Affect of Water on Utilization
Efficiency of Wood as a Fuel
in Terms of the Dry Weight of Wood Present



% moisture (wet weight basis) as received or as burned (C)

Source: The two curves here are simply the middle and bottom curves of Figure I A divided by the top curve of Figure I A.

(A) This curve includes the effect of the top curve but in addition shows a sort of practical maximum efficiency attainable in conventional boilers.

(B) Range of efficiencies for steam boilers using heating oil (large to small). This bar is placed here for comparison with the efficiency scale; ignore the % moisture scale.

(C) D.E. EARL (14) claims that it is customary in the timber trade to use a dry weight based moisture scale such that 50% moisture on Figure I A and I B would be called 100% moisture. To use this strange convention it is only necessary to change the bottom scales on these figures.

Likewise for wood, one should use the values represented by the middle line giving the maximum calorimetric value rather than the maximum practical values which are used in the government publications. The value for cross C, 3.2 Mkcal/Ton would seem to be a better choice for inter fuel comparisons. The height and width of the cross indicate estimates of the range in moisture content at time of burning for most firewood and the probable range in heats of combustion of average Brazilian woods. Remember, 5 kcal/g at 0% humidity is toward the upper range of typical woods. 4.5 kcal/g to 5 kcal/g.

We evaluate next the effect of the proposed higher value on Brazilian energy accounts along with the effect of other corrections.

Calculating Energy Equivalent of Wood

A sample calculation will be shown to identify clearly the procedure

1. Using given Brazilian values for 1976 (numbers rounded to avoid insignificant figures)

basic input: Firewood consumption (not counting charcoal) = 330Mm^3 steres

$\frac{\text{steres}}{\text{m}^3\text{ solid}}$ = .7,

dry weight density = .4 $\frac{\text{Ton}}{\text{m}^3\text{ solid}}$,

National average heat value at nominal 25% moisture = 2.5 Mkcal/Ton

wet weight density at 25% nominal moisture content = .53 $\frac{\text{T}}{\text{m}^3}$

10.8 Mkcal = 1 TEP

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a. (330M steres) x .7 = 230Mm^3 solid

$$230\text{Mm}^3 \times .53\ \frac{\text{Ton}}{\text{m}^3} = 122\text{ M Tons} \times \frac{2.5\text{ Mkcal}}{10.8\text{ Mkcal}}\left(\frac{\text{TEP}}{\text{Ton}}\right) = 28.2\text{ MTEP}$$

b. However, if one incorrectly uses the dry weight density

$$230\text{Mm} \times .4\ \frac{\text{Ton}}{\text{m}^3} = 92\text{M Tons} \times \frac{2.5\text{ Mkcal}}{10.8\text{ Mkcal}}\left(\frac{\text{TEP}}{\text{Ton}}\right) = 21.3\text{ MTEP}$$

The results circled are exactly the values published in BEN-78. If numbers aren't rounded the agreement is perfect. This same result is observed for all BEN-78 data, i.e., all years and all reports that agree with BEN-78 such as MEB-FINEP, etc. The error is present in the basic MEB-70 work from which all other reports derive.

The result of this error in procedure is a substantial under-representation of the energy value of firewood in the national picture. However, if we attempt the same calculation adopting the other recommendations in this paper the difference gets even larger.

Using a smaller conversion factor for steres/m^3 leads to a slight reduction but using the recommended heating value of wood leads to another substantial increase.

2. Calculating energy equivalent of Brazilian Firewood usage (excluding charcoal) using recommended values and correct procedure.

basic input: for 1976 330Mm^3 steres

but using:

	dry weight	25% M.C.	Heat value at 25% M.C.
.6 $\frac{\text{steres}}{m^3}$	.45 $\frac{\text{Ton}}{m^3}$ $\rightarrow$	.60 $\frac{\text{Ton}}{m^3}$	3.2 $\frac{\text{Mkcal}}{\text{Ton}}$
instead of			
.7	.4	.53	2.5

$$330\text{Mst} \times .6 = 196\text{Mm}^3 \times .6 \frac{\text{Ton}}{m^3} = 118\text{M Tons} \times \frac{3.2}{10.8} = 35 \text{ MTEP}$$

So 35 MTEP instead of 21.3 MTEP is the result

	approximate BEN-78		proposed here	
firewood	21.3	22%	35	31%
others (including charcoal)	78.8		78.8	
	99.1 MTEP		113.8 MTEP	

Total firewood consumption in energy equivalent is ~50% higher than currently indicated in BEN-78.

Comparison of two procedures:

Using Heating value of 0% moisture

Consider 1m^3 of dry wood with heating value of 4.6 Mkcal/Ton and dry weight density of .5 Ton/m^3

Heating value = .5 Ton x 4.6 Mkcal/Ton = 2.3 Mkcal

Using Heating value of 25% moisture

with same 1m^3 of wood now weighing .67 Ton and 3.2 Mkcal/Ton (from Fig. I-A)

Heating value = .67 Ton x 3.2 Mkcal/Ton = 2.1 Mkcal

These results show the 10% loss in heating value due to using wood at 25% moisture content. The recommended value 3.2 Mkcal/Ton was chosen on the basis of this relationship with respect to the probable 0% moisture content value for Brazilian wood. Apparently the FAO uses the 0% moisture content approach. It has the advantage of involving the simplest definitions.

The present Brazilian approach which uses 2.5 Mkcal/Ton takes into account additional efficiency losses in heat conversion but these losses are of the same nature as also occur in using petroleum for which such losses are not taken into account.

In comparing electricity usage to other energy uses in Brazilian national accounts it is the custom to count the oil equivalent value of the highly efficiently converted hydraulic power. This is reasonable since almost all electricity usage cannot be replaced simply by heat without passing through an inefficient heat to mechanical energy conversion.

One might make a somewhat parallel argument that wood stoves in principle could be replaced by much more efficient LPG stoves with perhaps a factor of 5 reduction in energy use. Then on this basis one might argue that the energy value of wood should be devalued by a factor of 5 in comparison to petroleum in much the same way as the intrinsic energy value of electricity is supervalued by a factor of about 3 in comparison to petroleum.

However, the efficiency of domestic cooking is extremely variable (10) and determining the best conversion factor for the Brazilian average would not be easy. Furthermore, and most importantly only about 50% of firewood usage is domestic cooking. The approximately 25% of firewood usage in industry is very different in terms of energy utilization efficiency and the technical possibilities are such that efficiencies in some cases approaching those for petroleum are possible. For this reason, national energy accounts should use a calorimetric value for the heating value of wood rather than a value representing some measure of current practical utilization efficiency.

Using the calorimetric value also tends to highlight the tremendous energy value in wood which is currently being used neither very efficiently nor in as many applications as practical given the uncertainties in petroleum dependence.

(10) Cooking Stoves: the state of the art; J. Goldemberg and R.I. Brown, 1979