PERGAMON

Energy Conversion & Management 40 (1999) 1141–1162

ENERGY CONVERSION & MANAGEMENT

Potential of biomass fuel conservation in selected Asian countries

S.C. Bhattacharya*, R.A. Attalage, M. Augustus Leon, G.Q. Amur, P.A. Salam, C. Thanawat

Energy Program, School of Environment, Resources and Development, Asian Institute of Technology, P.O. Box 4, Klong Luang, Pathumthani, 12120, Thailand

Received 30 June 1998; accepted 10 December 1998

Abstract

The potential of savings in the biomass consumed for energy in seven Asian countries—China, India, Pakistan, Nepal, Philippines, Sri Lanka and Vietnam—is estimated, if the centuries-old traditional methods of biomass use are reconsidered and an efficient, rational use is implemented. The present pattern and share of biomass consumption of different traditional biomass energy devices are recorded. The efficiency of traditional technologies and that of improved ones—technologies which are practically applicable or already in use somewhere else—are compared and the potential of biomass savings is calculated. The total biomass saving potential in all seven countries together has been estimated at 322 million tons/year © 1999 Elsevier Science Ltd. All rights reserved.

Keywords: Traditional cookstoves (TCSs); Improved cookstoves (ICSs); Biomass energy saving potential; Bagasse-fired boilers

1. Introduction

Energy from biomass normally has the biggest share in the supply of energy in rural areas of developing countries, fuelwood often accounting for a major fraction of it. In all the countries covered in this study, national energy consumption patterns reveal that biomass energy plays a key role in meeting the energy requirements of the rural population, including cooking needs

* Corresponding author. Tel.: 0066 2524 5418; fax: 0066 2524 5403.
E-mail address: bhatta@ait.ac.th (S.C. Bhattacharya)

PII: S0196-8904(99)00002-3

of households and the requirements of rural and village industries. Of the many different traditional technologies existing in the rural sectors, most have been identified as "inefficient" and there is room for numerous minor and often major improvements in efficiency.

The seven Asian countries covered in this study show large variations in size, population, GDP etc., but there is a heavy reliance on biomass based fuels in all these countries. The amount of biomass that can be saved through efficiency improvement can serve as a source of additional energy and can potentially substitute for fossil fuels to reduce net GHG emission.

This study attempts to assess the potential of biomass savings through efficiency improvement of biomass energy systems in seven selected countries of Asia, i.e., China, India, Pakistan, Philippines, Nepal, Sri Lanka and Vietnam.

2. Energy conservation potential in the domestic sector

Cooking is one area which consumes the major share of total biomass used in all developing nations. Traditional cookstoves commonly found in the Asian countries selected for this study are not only used for cooking but also for water heating, space heating, simultaneous cooking-and-space heating and even for providing light in some cases. The design and size of cooking stoves/combustion systems vary for different countries and communities.

2.1. Evaluation of biomass saving potential

Most of the traditional cookstoves in the seven countries covered have low efficiencies in the range of 5–15%. At present, a large share of biofuels in these countries is utilized in traditional cookstoves. The types of cookstoves being used may be broadly classified into: fuelwood-using, residue-using and charcoal-using stoves.

In the last few decades, scientific methods were applied to improve the performance of cookstoves. Many different types of improved cookstoves were introduced and propagated among the rural community. The potential saving of biomass used for cooking in these countries has been estimated by comparing the efficiencies of Traditional Cookstoves (TCSs) with those of Improved Cookstoves (ICSs).

The "efficiency" of cooking is a point which needs explanation. If the fire during cooking is used to provide room heat or light in addition to cooking, as in many cases, the question of efficiency cannot be considered purely on the basis of its effectiveness in providing heat for cooking. In this study, only the "cooking efficiency" has been considered and further services provided by the fire for room heating or lighting have not been taken into account.

In case the efficiency of a certain type of stove is not found anywhere in the literature, it is taken as the efficiency reported for a similar type of stove used in another country. However, such assumptions have been indicated wherever applicable.

Assuming that all traditional cookstoves (TCSs) are replaced by improved cookstoves (ICSs), the biomass saving potential can be estimated as:

Biomass saving potential = (amount of biomass currently used in TCSs) × (efficiency difference between TCS and ICS)/efficiency of ICS

2.2. Biomass saving potential with improved cookstoves

2.2.1. China

In the early eighties, China embarked on a national program on improved cookstove development in an effort to save biomass fuels. Within a decade of its implementation, more than 148 million households had acquired ICSs [10]. As reported by Yuan and Qing [42], 68% of the cookstoves used in the residential sector are improved ones, and the remainder are traditional. An estimated 80 million tons of fuelwood are being saved in the country annually with the use of these ICSs [30]. The different types of cookstoves used in the country and their reported efficiencies are given in Table 1.

Table 2 shows the selected efficiency values based on lower heating value [17], for different stoves and their estimated biomass energy saving potentials. As seen in the table, replacing the TCSs with ICSs can save 42.53 million tons of fuelwood and 80.36 million tons of agri-residues and 6.53 million tons of animal wastes. These potential savings are over and above the savings that have already been achieved so far through dissemination of ICSs. Use of charcoal for cooking is not considerable in China and, hence not taken into account while calculating the biomass saving potential. ICSs using animal dung as fuel are not popular in the country. However, if introduced, these ICSs could save approximately 2.9 million tons of animal dung in China.

2.2.2. India

In India, the total annual consumption of biofuels in cookstoves include 124.5 million tons of fuelwood, 38.4 million tons of agri-residues, 0.95 million tons of charcoal and 67.6 million tons of animal dung [35].

Table 1
Types and efficiencies of cookstoves in China

Type of stove	TCS/ICS	Efficiency (%)	Fuel type	Reference/remarks
Simple cookstove	TCS	13.0	Fuelwood, agri-res. & animal dung	a
Rice husk stove	TCS	16.0	Ricehusk	a
Saw dust stove	TCS	16.0	Sawdust	a
Charcoal stove	TCS	24.0	Charcoal	a
PT-I	ICS	40.9	Fuelwood, agri-res.	b
PT-II	ICS	38.7	Fuelwood, agri-res.	b
FL/CCS	ICS	28.0	Fuelwood, agri-res.	b
FL/PCS	ICS	38.0	Fuelwood, agri-res.	b
WS	ICS	40.0	Fuelwood, agri-res.	b
YS-I	ICS	35.0	Fuelwood, agri-res.	b
YS-II	ICS	40.0	Fuelwood	b
Suizhou-400	ICS	40.1	Fuelwood, agri-res.	b
WH	ICS	42.5	Agri-res.	b

[a] Assumed.
[b] FAO [18].

Table 2
Selected efficiencies of stoves and biomass saving potential in China. Based on the efficiency values of ICSs in India

Type of biomass	TCS/ICS	Present consumption[a] (million ton/year)	Assumed efficiency (%)	Saving potential (million ton/year)
Fuelwood	TCS	65.0	9.0	42.53
	ICS	80.0	37.5	
Agri-residues	TCS	133.0	15.0	80.36
	ICS	170.0	37.9	
Charcoal	TCS	0.1	24.0	0.04
	ICS	0.0	37.5	
Animal dung	TCS	10.0	13.0	6.53
	ICS	0.0	37.5	

[a] During 1993; source: Yuan-bin [42].

With the implementation of a popular Improved Chulha program in 1983, more than 23.6 million ICSs have been distributed throughout the rural population. This already saves about 11.5 million tons of fuelwood annually [32]. There are more than 30 different types of ICSs developed in various parts of the country. However, only those types of which at least 50000 stoves have been disseminated are considered here. Efficiencies of TCSs are in the range of 7–16%. Details of the types and efficiencies of such cookstoves in India are given in Table 3.

Table 4 shows the selected efficiencies for cookstoves and estimated biomass saving potential in India. The study reveals a large saving potential for fuelwood of about 66 million tons, accounting for 54.4% of the present consumption. Also, 13.06 million tons of agri-residues, 0.33 million tons of charcoal and 26.81 million tons of animal wastes can be saved if the existing TCSs are replaced with more efficient ICSs. The amount of charcoal used for cooking purposes is not considerable, and there seems to be very few ICS designs available in the country which can use charcoal as fuel.

2.2.3. Nepal

Biomass fuels are vital sources of energy in Nepal, accounting for 92.2% of the total energy consumption in the country during 1992/93 [13]. About 11 million tons of fuelwood, 3.2 million tons of crop residues, 2 million tons of animal dung and 29 kt of charcoal were used in the country during 1992/93 [36].

Traditionally, Agenu (open fire with an iron tripod) and Chulo (closed mud/stone stove without chimney) stoves have been widely used for cooking and heating purposes in Nepal. Various studies conducted on cookstoves dissemination and implementation programs in Nepal show that the traditional cookstoves possess efficiency of 8–12% as compared to 20–27% in the case of improved cookstoves [11]. The different types of stoves used in the country and their efficiencies are given in Table 5.

Table 6 presents the selected efficiencies for cookstoves and the estimated biomass saving potential. Approximately 30% saving potential has been estimated for all the fuels used—fuelwood, agri-residues, charcoal and animal wastes. Use of charcoal for cooking is only about 16 kt annually and, hence, is neglected.

2.2.4. Pakistan

In Pakistan, a household survey conducted in 1989 found 79% of the rural population and 55% of the urban population using fuelwood for cooking and heating. Wood accounted for 50% of the domestic energy consumption, while agricultural residues and animal dung accounted for 34.3% during 1987. The most common TCS, popularly known as the Horse-shoe stove, is reported to have efficiency in the range of 5–13% [21, 43]. An average efficiency of 9% based on higher heating value is taken for TCS in this study in the calculation of biomass saving potential.

It is claimed that a newly developed ICS, a one pot metal stove with aluminium pot has a thermal efficiency of 42%; also, a one pot metal stove with chimney has been reported to have

Table 3
Types and efficiencies of cookstoves in India

Type of stove	TCS/ICS	Efficiency (%)	Fuel type	Reference/remarks
Three-stone open fire	TCS	8.0	Fuelwood, crop res., dung	a
Simple mud chulha	TCS	12.0	Fuelwood, dung	b
Traditional Indian chulha	TCS	12.5	Fuelwood, crop res., dung	b
Sheet metal un-insulated chulha	TCS	18.0	Charcoal	c,a
Mud coated bucket chulha	TCS	21.0	Charcoal	c,a
Economical chulha	ICS	22.0	Fuelwood, crop res., dung	b,c
Abhinav/Jetan	ICS	22.0	Fuelwood	d
	ICS	11.4	Dung	d
ASTRA	ICS	30.0	Fuelwood	d
	ICS	14.6	Dung	d
DOACHHI	ICS	20.2	Fuelwood	d
	ICS	17.4	Dung	d
HARSHA	ICS	24.8	Fuelwood	d
	ICS	18.5	Dung	d
	ICS	21.9	Charcoal	d
LAXMI	ICS	22.0	Fuelwood	d
	ICS	14.7	Charcoal	d
MAMTA	ICS	24.0	Fuelwood	d
	ICS	16.0	Dung	d
	ICS	14.0	Mustard stem	d
PRIAGNI	ICS	26.0	Fuelwood	d
SUGAM-II	ICS	28.2	Fuelwood	d
	ICS	24.2	Dung	d
SUGAM SEVA	ICS	25.1	Fuelwood	d
	ICS	23.0	Dung	d
SUKHAD	ICS	25.0	Fuelwood	d
	ICS	20.6	Dung	d
UDAI	ICS	20.0	Fuelwood	d
	ICS	16.4	Dung	d

[a] Assumed.
[b] Lepeleire et al. [29].
[c] UNESCO [44].
[d] FAO [17].

Table 4
Selected efficiencies of stoves and biomass saving potential in India

Type of biomass	TCS/ICS	Present consumption[a] (million ton/year)	Assumed efficiency (%)	Saving potential (million ton/year)
Fuelwood	TCS	119.50	10.8	65.95
	ICS	5.00	24.1	
Agri-residues	TCS	36.86	10.2	15.97
	ICS	1.54	18.0	
Charcoal	TCS	0.95	19.5	0.33
	ICS	0.00	—	
Animal dung	TCS	64.90	10.8	26.81
	ICS	2.70	18.4	

[a] During 1990; source: Parashar and Narang [35].

44% efficiency [24]. These efficiency values appear to be rather too high. Also, it is not clear whether the efficiencies are based on lower or higher heating values of fuel. In the absence of reliable information on efficiencies of ICSs in Pakistan, a conservative efficiency of 24% has been assumed, based on the efficiency values available for India, in the calculation of biomass saving potential.

About 72% of the total biomass fuel used in Pakistan is consumed in Horse-shoe stoves. The remaining types of TCSs may be assumed to use another 4% of biomass. Thus, approximately 76% of the total biomass fuels used in Pakistan is used in the traditional cookstoves, consuming 48.4 million tons of biomass annually. Fuelwood is the main source of energy for cooking, accounting for about 27 million tons during 1990–91. Charcoal used for cooking was a meager 41 kt [3].

The different types of cookstoves used in Pakistan and their efficiencies are given in Table 7. The selected values of efficiencies and the estimated biomass saving potential are presented in Table 8. An approximate 60% biomass saving potential has been estimated, in general. From

Table 5
Types and efficiencies of cookstoves in Nepal

Type of stove	TCS/ICS	Efficiency (%)	Fuel type	Reference/remarks
Agenu (Open fire stove)	TCS	8.9	Fuelwood, residues, dung	a
Chulo/mud stove	TCS	12.0	Fuelwood, residues	b,c
Semi-closed stove (DCS type)	ICS	13.0	Fuelwood	a
Closed stove with chimney and water heating system (Blacksmith Stove)	ICS	14.2	Fuelwood	a
New Nepali Chulo	ICS	17.8	Fuelwood, residues	d,c

[a] Boiling Point, April 1997 [8].
[b] Energy Synopsis Report [13].
[c] Assumed.
[d] UNESCO [44].

Table 6
Selected efficiencies of stoves and biomass saving potential in Nepal

Type of biomass	TCS/ICS	Present consumption[a] (kt/year)	Assumed efficiency (%)	Saving potential (kt/year)
Fuelwood	TCS	10 088	10.5	3026
	ICS	101	15.0	
Agri-residues	TCS	2996	10.5	1229
	ICS	34	17.8	
Charcoal	TCS	16	—	—
	ICS	0	—	
Animal dung	TCS	1849	8.9	752
	ICS	20	15.0	

[a] During 1992–93; source: Sharma [36].

the data available, it can be seen that charcoal use for cooking is only 41 kt annually, and the stoves using charcoal are already improved. Hence, there seems to be less scope for any savings with the use of charcoal as cooking fuel unless the efficiency of the existing charcoal stove is further improved.

2.2.5. Philippines

Of the 33 million tons total of biomass used for energy in the Philippines in 1995, about 22.7 million tons or 73% were consumed by the household sector for cooking and heating purposes [34]. Fuelwood constituted the major share at 81% of the total household biomass energy consumption. The use of animal dung in the household sector is negligible in the Philippines [9]. It has been assumed that TCSs in the country consume 80% of the total biomass consumption for household cooking.

The different types of cookstoves used in the Philippines and their efficiencies are given in Table 9. Table 10 shows the selected values of efficiencies and the estimated biomass saving

Table 7
Types and efficiencies of cookstoves in Pakistan

Type of stove	TCS/ICS	Efficiency (%)	Fuel type	Reference/remarks
Horse-shoe stove	TCS	9.0	Fuelwood, residues, dung	a
Tandoor oven	TCS	15.0	Fuelwood	b,c,e,d
Improved Tandoor oven	ICS	25.0	Fuelwood	b,c,e,d
Saw dust stove	ICS	19.0	Sawdust	b,d
Charcoal stove	ICS	21.0	Charcoal	b,d
Improved single-pot/multi-pot stove	ICS	24.0	Fuelwood, residues, dung	b,f,d

[a] Imtiaz [21], UNDP [43].
[b] Amur and Bhattacharya [47].
[c] FAO [15].
[d] Assumed.
[e] FAO [14].
[f] FAO [16].

Table 8
Selected efficiencies of stoves and biomass saving potential in Pakistan

Type of biomass	TCS/ICS	Present consumption[a] (million ton/year)	Assumed efficiency (%)	Saving potential (million ton/year)
Fuelwood	TCS	25.80	9.0	16.32
	ICS	0	24.5	
	Tandoor	1.25	15.0	0.50
	Improved Tandoor	0	25.0	
Agri-residues	TCS	8.05	9.0	4.68
	ICS	0.07	21.5	
Charcoal	TCS	0	—	0
	ICS	0.04	21.0	
Animal dung	TCS	13.30	9.0	8.31
	ICS	0	24.0	

[a] During 1991; source: Amur [3].

potential in the Philippines. Major saving potential appears to be in fuelwood, amounting to about 7.4 million tons annually.

2.2.6. Sri Lanka

In Sri Lanka also, the household sector is the largest biomass energy consumer, with an annual consumption of 9.95 million tons (1993) of biomass. Biomass fuels are the major source of energy for the rural population for domestic cooking. In 1993, the country consumed 8.961 million tons of fuelwood and 0.994 million tons of agri-residues in the household sector [27]. Use of charcoal and animal dung for domestic cooking is negligible. Table 11 gives the types and efficiencies of cookstoves used in Sri Lanka. Assuming that 20% of the total fuelwood used in the domestic sector is used in the ICSs and that no agri-residues are burnt in ICSs, the biomass saving potential has been estimated as presented in Table 12.

Table 9
Types and efficiencies of cookstoves in the Philippines

Type of stove	TCS/ICS	Efficiency (%)	Fuel type	Reference/remarks
Tripod/Three stone stove	TCS	6.5	Fuelwood, agri-residues	a
Half-cylinder stove	TCS	9.5	Fuelwood, agri-residues	a
Charcoal-using clay stove	TCS	18.0	Charcoal	a
Sawdust-using clay/cement stove	TCS	10.5	Sawdust	a
Lorena stove	ICS	22.0	Fuelwood	a
CPU stove	ICS	17.5	Ricehusk	a
Kalandan	ICS	13.0	Ricehusk	a
Bioflame	ICS	13.0	Ricehusk	a
Bioflame	ICS	20.0	Charcoal	a
QB stove	ICS	37.0	Charcoal	a
FPRDI	ICS	33.0	Charcoal	a

[a] NCED [34].

Table 10
Selected efficiencies of stoves and biomass saving potential in the Philippines

Type of biomass	TCS/ICS	Present consumption[a] (million ton/year)	Assumed efficiency (%)	Saving potential (million ton/year)
Fuelwood	TCS	11.64	8.0	7.41
	ICS	2.91	22.0	
Agri-residues	TCS	2.64	8.0	1.18
	ICS	0.66	14.5	
Charcoal	TCS	0.62	18.0	0.25
	ICS	0.15	30.0	

[a] During 1995; source: DoE [50].

Saving potential in Sri Lanka amounts to about 2.24 million tons of fuelwood and 0.497 million tons of agri-residues if the traditional cookstoves are replaced with new improved ones. There seems to be no ICS design available in Sri Lanka which could use agricultural residues as fuel. However, if the ICS designs available in India are introduced, a considerable biomass saving, estimated at about 0.41 million tons of agricultural residues, could be realised. Charcoal use for cooking in Sri Lanka is negligible.

2.2.7. Vietnam

Biomass energy has been a vital source of energy in Vietnam. Fuelwood constituted the major amount, at 81% of the total 34.7 million tons of biomass used in the country in 1990 [22]. Agricultural residues and charcoal accounted for the remainder, at 17.8 and 1.1%, respectively. Use of animal dung as direct fuel is almost negligible [25].

Table 13 shows the types and efficiencies of cookstoves used in Vietnam. The biomass saving potential with improved stoves using charcoal is neglected in this study. The assumed efficiency values and estimated biomass saving potential are given in Table 14. The estimated biomass saving potential in the country is large, with 14.753 million tons of fuelwood and 3.828 million

Table 11
Types and efficiencies of cookstoves in Sri Lanka

Type of stove	TCS/ICS	Efficiency (%)	Fuel type	Reference
Three-stone open fire stove	TCS	8.0	Fuelwood, agri-residues	a
Single and two pot mud stove	TCS	13.0	Fuelwood, agri-residues	b,a
Anagi stove	ICS	18.0	Fuelwood	b,a
Ceylon charcoal stove	ICS	30.0	Charcoal	c
Sarvodaya two pot/Tungu lowon stove	ICS	22.0	Fuelwood	b,a
CISIR's single pot stove	ICS	24.0	Fuelwood	c,a
IDB's single pot chimneyed stove	ICS	20.0	Fuelwood	d

[a] Assumed.
[b] FAO [16].
[c] UNESCO [44].
[d] Lepeleire et al. [29].

Table 12
Selected efficiencies of stoves and biomass saving potential in Sri Lanka

Type of biomass	TCS/ICS	Present consumption[a] (million ton/year)	Assumed efficiency (%)	Saving potential (million ton/year)
Fuelwood	TCS	4.48	10.5	2.24
	ICS	4.48	21.0	
Agri-residues	TCS	0.99	10.5	0.41
	ICS	0	18.0	

[a] During 1993; source: Kumaradasa [27].

tons of agri-residues, accounting for more than 70% of present consumption. From the data available, it can be seen that the stoves using charcoal are already improved. Hence, there seems to be less scope for any savings with the use of charcoal as cooking fuel unless the efficiency of the existing charcoal stove is further improved.

3. Energy conservation potential in the industrial/commercial sector

The main biomass combustion devices considered in the industrial sector are: bakery ovens, boilers, furnaces and kilns. The energy conservation methods normally applicable for these—apart from design of the device itself—are: excess air control, exhaust flue gas temperature control and moisture control in biomass fuels.

3.1. Biomass saving potential with improved bakery ovens

Various designs of baking ovens exist in the Asian countries depending upon the requirement and cultural practices. Very little work has been performed on either the improvement of traditional ovens or on the development of new, efficient ovens. It is generally believed that there is considerable room for improvement in the existing ovens. Much of the

Table 13
Types and efficiencies of cookstoves used in Vietnam

Type of stove	TCS/ICS	Efficiency (%)	Fuel type	Reference/remarks
Three stone stove	TCS	8.0	Fuelwood, agri-residues	a
Tripod stove	TCS	10.0	Fuelwood, agri-residues	b
Ash insulation stove	ICS	32.0	Fuelwood, Charcoal	c,a
Ash insulated double-walled clay stove	ICS	32.0	Fuelwood, Charcoal	c
Multi-fuel stove	ICS	33.0	Fuelwood, agri-residues, saw dust	c
Brick stove	ICS	34.0	Fuelwood, agri-residues	c

[a] Assumed.
[b] Khoa [25].
[c] ESCAP [12].

Table 14
Selected efficiencies of stoves and biomass saving potential in Vietnam

Type of biomass	TCS/ICS	Present consumption[a] (million ton/year)	Assumed efficiency (%)	Saving potential (million ton/year)
Fuelwood	TCS	20.83	9.0	15.15
	ICS	2.31	33.0	
Agri-residues	TCS	5.23	9.0	3.82
	ICS	0.58	33.5	
Charcoal	TCS	0	—	—
	ICS	0.19	32.0	

[a] During 1991; source: Khoa [25] and IoE [22].

inefficiency is due to high levels of excess air and poor distribution and circulation of heat in the oven.

Presently, there is no agreed standard for testing of wood-fired bakery ovens. Actual consumption of fuel depends on the flour type, type of bread being baked, baker's skill, type and size of oven, type of wood used and moisture content of wood. Bakers usually evaluate their ovens in terms of convenience of use, evenness of heat distribution, warm-up time, range of products that can be produced, ease of heat control and wood consumption.

The scope in fuel conservation in ovens lies in improving the efficiency of these ovens by increasing the batch size, using more baking layers (shelves) in the oven, using dry fuelwood, enhancing better fuelwood combustion etc. Joseph [23] pointed out that by introducing improved ovens in parts of Asia, fuelwood consumption by bakery ovens in the region could easily be reduced by 40%. Accordingly, in this study, it has been assumed that the biomass saving potential with improved ovens is 40%; estimates of potential saving for four Asian countries are presented in Table 15.

Table 15
Total biomass saving potential with improved ovens

Country	Fuelwood consumption in ovens[a] (kt/year)	Estimated fuelwood saving potential (%)	Fuelwood saving potential (kt/year)
China	200.0	40	80.0
India	3500.0	40	1400.0
Nepal[b]	27.5	40	11.0
Pakistan[c]	30.0	40	12.0
Philippines	73.4	40	29.3
Total	3830.9		1532.3

[a] UNDP [43].
[b] Available data includes consumption in "Furnaces", "Kilns", and "Ovens". Hence a share of 1:1:1 has been assumed.
[c] MUCET Estimates [49].

Data on fuelwood consumption in ovens for other countries is not available and hence, the saving could not be estimated.

3.2. Biomass saving potential in wood-fired boilers

Generally, there are three ways of improving boiler efficiency in wood-fired boilers: by reducing excess combustion air to an optimum level, by heat recovery from exhaust flue gases and by reducing the moisture content of fuel.

Liadpratom [31] found that the efficiency of a boiler using woodfuel was 66.2%, and reducing the excess air level from 263 to 50% could enhance the boiler efficiency to 72.5%. Tanawat Chaiwatanorat [41] has estimated a woodfuel saving of 15.4% by combined flue gas heat recovery and excess air control in the wood-fired boilers of Thailand.

In a study by Bhattacharya [6], a woodfuel saving of 6% was estimated in a boiler using wood for a reduction of wood moisture level from 35 to 15% (wet basis). He also reported a wood saving potential of 10% by reducing the excess air from 200 to 40% at an exhaust gas temperature of 200°C.

Based on the above review, the average biomass saving potential of wood-fired boilers has been assumed at 10%. The saving potential in these countries based on the above assumption has been presented in Table 16.

The total firewood saving potential in wood-fired boilers in the selected countries, thus, works out to an estimated 0.591 million tons/year.

3.3. Biomass saving potential in bagasse-fired boilers

The sugar industry is an energy intensive one and is one of the major agro-industries in most of the countries selected for this study. The industry produces bagasse, after squeezing juice, as a by-product, which is directly burnt in the boilers to power the whole plant. Energy

Table 16
Biomass saving potential in wood-fired boilers

Country[a]	Fuelwood consumption in boilers[b] (million ton/year)	Assumed fuelwood saving potential (%)	Fuelwood saving potential (million ton/year)
China (1993)	3.000	10	0.300
India (1990)	1.750	10	0.175
Nepal (1992–93)	0.153	10	0.015
Pakistan (1991)	0.004	10	0
Philippines (1995)	0.712	10	0.071
Sri Lanka (1993)	0.011	10	0.001
Vietnam (1991)	0.582	10	0.058
Total	6.212		0.621

[a] Year in parentheses refers to data for that particular year.
[b] Yuan and Qing [42], Narang [33], Sharma [36], Cabrera [9], Kumaradasa [28], IoE [22].

conservation in bagasse-fired boilers is usually achieved by all three techniques: excess combustion air control, exhaust flue gas heat recovery and moisture control in fuel/bagasse.

An increase in moisture content of the fuel will naturally reduce the amount of heat liberated by the combustion reaction per unit mass of the fuel. In addition, a considerable amount of energy from the fuel is consumed as latent heat by the evaporating moisture. Biomass drying, therefore, becomes a valid option to increase the efficiency of the combustion system.

A considerable amount of energy is lost in boiler exhaust gases, normally at a temperature of 200–250°C, in the form of sensible heat. An attempt to save a part of it, logically, pays off. By utilizing part of the otherwise wasted heat energy by incorporating a waste heat recovery system, the overall thermal efficiency of the boiler system could be considerably enhanced. Energy analysis shows that about 7–8% of bagasse produced at sugar mills can be saved by employing bagasse dryers [2, 40]. A typical bagasse saving of 6.68% has been reported in a Sugar Mill in Pakistan with bagasse drying [1]. Viqar [46] estimated a 10% saving potential of bagasse in a Sugar Mill in Pakistan by reducing the moisture content of bagasse from 49.7 to 25%.

Various studies in Thailand showed that the excess air level in sugar mills varies from 80 to 170% [45]. Excess air levels in bagasse-fired boilers in Pakistan have been reported to be 35–240% [37], and the figures for the Philippines range between 129–300% [34]. Any effort to bring this level to the optimum 40–50% will considerably increase the efficiency of the boiler. Tanawat [41] reports a saving of 4% by controlling excess air, typically from 200 to 40%. For estimating the energy conservation potential of bagasse-fired boilers in this study, a combined saving potential of 12% has been assumed for all the countries with excess air control and exhaust heat recovery for bagasse drying. The total bagasse saving potential in all the selected countries has been estimated at about 3.84 million tons (Table 17).

Table 17
Biomass saving potential in bagasse-fired boilers

Country[a]	Bagasse consumption in boilers[b] (million ton/year)	Bagasse saving potential	
		%	Million ton/year
China (1993)	0	0	0
India (1990)	36.000	12	4.320
Nepal (1992–93)	0.005	12	0.001
Pakistan (1991)	6.905	12	0.828
Philippines (1995)	5.969	12	0.716
Sri Lanka (1993)	0.272	12	0.032
Vietnam (1991)	0.123	12	0.015
Total	49.274		5.913

[a] Year in parentheses refers to data for that particular year.
[b] Yuan and Qing [42], Narang [33], Sharma [36], Amur and Bhattacharya [4], Cabrera [9], Kumaradasa [28], IoE [22].

3.4. Biomass saving potential in ricehusk-fired boilers

Ricehusk is used as a boiler fuel in three ways. (i) In many older mills, steam from husk-fired boilers is used in steam engines or turbines to provide mechanical power for rice milling. (ii) In some of the medium sized mills, steam from husk-fired boilers is used as a source of heat for the parboiling of paddy. (iii) In some larger mills, steam from husk-fired boilers is used in steam engines or turbines to generate electricity. In several developing countries, husk-fired steam power plants at large rice mills are providing electric power for adjacent communities and/or industries, as well as for their own operation [7].

Rice husk is one of the most difficult biomass fuels to burn efficiently because of its high ash content. Combustion processes leave unburned carbon for different reasons, resulting in poor energy recovery. Analysis in a ricehusk combustion system in the USA revealed that 42% of the char/ash was unburned carbon [47]. Improvements in combustion systems to reduce the unburned carbon tends to boost combustion efficiency.

The performance of a ricehusk-fired boiler, like wood-fired and bagasse-fired boilers, can also be increased by controlling excess air and recovering heat from exhaust flue gases. It has been reported that about 14.1% ricehusk saving has been achieved in a ricehusk-fired boiler in Thailand by recovering heat from flue gases to heat feed water [39]. Tanawat [41] estimated that in Thailand, 3% of ricehusk can be saved in boilers by controlling excess air from 100 to 50%. A 10% saving is assumed in this study for all the selected countries. With that, the total ricehusk saving potential has been estimated as presented in Table 18.

The total saving potential of rice husk in the selected countries is estimated at about 0.0614 million tons annually.

3.5. Biomass saving potential with improved furnaces

Furnaces are common combustion devices that are often used for serving different purposes. There are a variety of biomass furnaces used in all the countries covered for a variety of applications. Applications generally include: drying of agro-products (like cocoa, coconut, coffee, etc.), processing of tea leaves and spices, rubber sheet smoking, tobacco leaf curing, fish smoking, etc., and for handicrafts industries (brass and bronze articles making, glassware and ceramics).

Large quantities of biomass (usually firewood and agri-residues) are consumed in different types of furnaces, in general, with low efficiencies and technical levels. There is considerable scope for improvement in their operating efficiencies.

The main energy conservation measures in tobacco curing are two-fold: (i) proper insulation of the curing barn structure and (ii) front furnace cover. Test results indicated a combined energy saving potential of 22% [20]. The “Energy Conservation in Tobacco Curing” project in Thailand has estimated that the energy cost of traditional flue-cured barns can be reduced by 22% with energy conservation remedies [38]. Hirun et al. [20] report a thermal efficiency of 19% for a typical firewood-using traditional barn in Thailand. Use of better insulation together with front furnace cover enhanced the efficiency to 24%. A study performed in India [5] estimated the amount of fuelwood used for tobacco curing in the country to be 0.438 million tons per annum. A new furnace design, locally known as the JTS-ILTD System, has

Table 18
Biomass saving potential in ricehusk-fired boilers

Country[a]	Ricehusk consumption in boilers[b] (kt/year)	Ricehusk saving potential (%)	Ricehusk saving potential (kt/year)
China (1993)	100.00	10	10.00
India (1990)	0	0	0
Nepal (1992–93)	17.70	10	1.77
Pakistan (1991)	0	0	0
Philippines (1995)	6.82	10	0.68
Sri Lanka (1993)	50.00	10	5.00
Vietnam (1991)	114.00	10	11.40
Total	288.52		28.85

[a] Year in parentheses refers to data for that particular year.
[b] Yuan and Qing [42], Narang [33], Sharma [36], Amur and Bhattacharya [4], Cabrera [9], Kumaradasa [28], IoE [22].

been reported to have saved about 25% of fuelwood consumption compared to the traditional system [5].

The British-American Tobacco Company in Kenya reduced the fuel consumption in small-holder curing from about 15 kg of wood/kg of cured leaf to 6 kg, a saving of 60% [14]. Conservation measures include insulation of barn walls, optimization of ventilation rates by reducing air flows, modifications to furnace design and improvements in heat exchange surfaces.

Coffee drying and roasting furnaces also use fuelwood, and the scope for efficiency improvements is considerable. Fish smoking and drying furnaces have been used in many countries, but data about their performance are hardly available. However, reductions in fuel consumption of 50% have been recorded [14]. Koopmans [26] pointed out that as compared with traditional ones, the improved furnaces, in general can save 25–50% of the total biomass consumption [15].

This study assumes an average value of 35% fuel conservation potential for estimating the biomass saving potential of furnaces in the selected countries; the estimates are presented in Table 19. The estimated saving potential from improved furnaces is about 4.53 million tons of fuelwood, 2.971 million tons of agri-residues and 1.75 million tons of animal dung in six of the countries covered.

3.6. Biomass saving potential with improved kilns

Kilns are basically large ovens used in industries e.g., brick-making, lime production, etc. The brick kiln is one of the oldest technologies being used in Asian countries. Bricks are produced at the cottage, village and rural enterprise levels, with varying technologies depending on the size and scale of production. Brick kilns used in all these countries consume a variety of fuels for their operation, including firewood, bagasse, ricehusk and coal. However, our interest is confined to kilns using only biomass for their operation.

Brick kilns are devices that consume large quantities of biomass. In general, two types of

Table 19
Total biomass saving potential with improved furnaces

Country[a]	Biomass fuel type	Present biomass consumption in furnaces[b] (million ton/year)	Assumed biomass saving potential (%)	Biomass saving potential (million ton/year)
China (1993)	Fuelwood	9.980	35	3.493
	Agri-residues	1.000	35	0.350
	Charcoal	0.090	35	0.031
India (1990)	Fuelwood[c]	4.125	35	1.444
	Agri-residues[c]	5.000	35	1.750
	Charcoal	1.400	35	0.490
	Animal dung	5.000	35	1.750
Nepal (1992–93)	Fuelwood[d]	0.079	35	0.027
	Agri-residues	0.004	35	0.001
	Charcoal	0.012	35	0.004
Pakistan (1991)	Fuelwood	1.940	35	0.679
	Agri-residues	4.254	35	1.489
Philippines (1995)	Fuelwood	0.302	35	0.105
	Agri-residues	1.018	35	0.356
Sri Lanka (1993)	Fuelwood	1.054	35	0.369
	Agri-residues	0.031	35	0.011
Vietnam (1991)	Fuelwood	1.667	35	0.583
	Agri-residues[e]	0.132	35	0.046
	Charcoal	0.205	35	0.072
Total	Fuelwood	19.147		6.701
	Agri-residues	11.439		4.003
	Charcoal	1.707		0.597
	Animal dung	5.000		1.750

[a] Year in parentheses refers to data for that particular year.
[b] Yuan and Qing [42], Narang [33], Sharma [36], Amur and Bhattacharya [4], Cabrera [9], Kumaradasa [28], IoE [22].
[c] Available data includes consumption in "Kilns". Hence a share of 1:1 has been assumed.
[d] Available data includes consumption in "Furnaces", "Kilns", and "Ovens". Hence a share of 1:1:1 has been assumed.
[e] Available data includes consumption in "Boilers". Hence a share of 1:1 has been assumed.

kilns are commonly used for firing bricks in the Asian region—the Batch type Intermittent Kiln (like clamp or updraft model) and the Continuous type with permanent structure and fixed or movable chimneys, like the Bull's Trench Kiln, the High Draft (HD) Kiln and the Hoffmann Kiln.

Intermittent type brick kilns are less efficient because a large amount of heat is lost in flue gases, from open furnaces, from cooling of the fired bricks and from poor firing practices. The thermal efficiencies of these kilns are low, with fuel requirements varying widely depending on size of the kiln, raw clay composition, size of brick, firing duration and firing temperature. The Bull's Trench Kiln, on the other hand, utilizes the heat in flue gases in pre-heating the bricks, and heat from the cooling zone is utilized in preheating the fresh air required for burning of the fuel at the firing zone. The fire travel and draught can be easily controlled in continuous kilns, but there is much less control in clamp type kilns.

Energy savings in kilns can primarily be achieved by design modifications to allow for complete enclosure of the flame and excess air control. Widely varying data are found in the literature for Specific Energy Consumption (SEC) values. This can be reasonably attributed to differences in heating value of coal, size and weight of bricks, quality of fired bricks, etc. Some of the efficiency improvement measures which were found to be effective include: adding roofs to clamps, providing permanent walls that are insulated with mud and a biomass residue (such as rice husk), increasing the height of the kilns, enclosing the firebox and adding a grate to the firebox. Considerable energy saving has been reported by Svenningson [48] when small pieces of wood were used and burning rate was carefully controlled. Increasing the height of the brick setting in a Bull's Trench kiln may also lead to energy savings [26]. In Sri Lanka, about 31% of fuelwood was saved in a brick kiln with some modifications done in controlling combustion air [15]. A fuelwood saving of 15% was reported in a kiln with the provision of a proper grate and regulation of primary and secondary air [26].

Lime making is yet another area which uses kilns similar to the ones used in brick/tile making. The kilns used are rectangular or cylindrical in shape, and are made from mud and bricks. Traditional limestone kilns are loaded with layers of limestone and fuelwood/coal in sandwich form, and the fire is started from below. Thermal efficiency of about 15–25% have been reported for small kilns [14]. Indonesian batch and continuous kilns are estimated to have an efficiency of 17 and 26%, respectively. An improved design developed in India is reported

Table 20
Biomass saving potential with improved kilns

Country[a]	Biomass fuel type	Present biomass consumption in kilns[b] (million ton/year)	Assumed biomass saving potential (%)	Biomass saving potential (million ton/year)
China (1993)	Fuelwood	15.000	35	5.250
India (1990)	Fuelwood[c]	4.125	35	1.444
	Agri-residues[c]	5.000	35	1.750
Nepal (1992–93)	Fuelwood[d]	0.027	35	0.010
Pakistan (1991)	Fuelwood	0.010	35	0.003
	Agri-residues	0.863	35	0.302
Philippines (1995)	Fuelwood	0.008	35	0.003
	Agri-residues	0.002	35	0.001
Vietnam (1991)	Agri-residues[e]	0.114	35	0.040
Total	Fuelwood	19.170		6.710
	Agri-residues	5.979		2.093

[a] Year in parentheses refers to data for that particular year.
[b] Yuan and Qing [42], Narang [33], Sharma [36], Amur and Bhattacharya [4], Cabrera [9], IoE [22].
[c] Available data includes consumption in "Furnaces". Hence a share of 1:1 has been assumed.
[d] Available data includes consumption in "Furnaces", "Kilns", and "Ovens". Hence a share of 1:1:1 has been assumed.
[e] Available data includes consumption in "boilers". Hence a share of 1:1 has been assumed.

to be saving 30% of fuel in comparison with traditional kilns. In general, a well-designed kiln can have an efficiency twice or even thrice that of the traditional ones, although the investment cost is significantly higher.

In the seven countries under consideration, a total of 17.05 tons of fuelwood and 0.4 tons of ricehusk are reportedly consumed in the traditional kilns. There exists, however, a large fuel saving potential. It may be achieved in two ways:

1. by improving the performance of existing types of kilns with measures such as better insulation, better design of firing chambers, including internal fuels like ricehusk in the bricks, better control of flue gases in the kilns etc.,
2. by substituting existing types of inefficient kilns with the efficient type kilns.

With the second option, the biomass saving potential is calculated for individual countries, and the results are presented in Table 20. While considering substitution of the existing types of kilns with more efficient types, a consistency is to be maintained on the capacity of the kilns. Substituting a large Bull's Trench kiln, for example, with a Hoffman kiln may not be a good option in view of the large difference in their capacities.

For small-scale brick making, while replacing existing clamp/scoved kilns with improved type kilns, the best choice in terms of the largest efficiency improvement would be to go for the Vertical Chinese Kiln. Although the Vertical Chinese Kiln uses coal fines as fuel and has not been used with woodfuels [19], it is assumed that it can also be used with woodfuels. The potential fuel saving in this case would be 60–88%. Similarly, potential fuel savings if Hoffman kilns are replaced with Vertical Chinese Kilns will be about 60%. Replacing the Bull's Trench kilns with High Draught kilns is known to offer a saving of 30%.

From the above evaluations, a conservative saving potential of 35% has been assumed for all seven countries, and the saving potential in that case will be an estimated 6.1 million tons per annum. Table 20 gives the country-wise biomass consumption in brick kilns and saving potential details. China and India are the two countries that offer more than 90% of the total

Table 21
Sector-wise biomass saving potential in the selected countries (million tons/year)

					Industrial									
	Domestic cooking				Ovens	Boilers			Furnaces				Kilns	
Country	Wood	Residues	Charcoal	Dung	Wood	Wood	Bagasse	Ricehusk	Wood	Residue	Charcoal	Dung	Wood	Residues
China	42.47	76.85	—	2.93	0.08	0.30	—	0.01	3.49	0.35	0.03	—	5.25	—
India	65.04	13.06	—	26.81	1.40	0.18	4.32	—	1.44	1.75	0.49	1.75	1.44	1.75
Nepal	3.03	1.23	0.00	0.75	0.01	0.02	0.00	0.00	0.03	0.00	0.00	—	0.01	—
Pakistan	16.82	4.68	0.00	8.31	0.01	—	0.83	—	0.68	1.49	—	—	0.00	0.30
Philippines	7.41	1.18	0.25	—	0.03	0.07	0.72	0.00	0.10	0.36	—	—	0.00	0.00
Sri Lanka	2.24	0.41	—	—	—	0.00	0.03	0.01	0.37	0.01	—	—	—	—
Vietnam	15.15	3.82	—	—	—	0.06	0.01	0.01	0.58	0.05	0.07	—	—	0.04
Total	152.16	101.23	0.25	38.80	1.53	0.62	5.91	0.03	6.70	4.00	0.60	1.75	6.71	2.09

Table 22
Total biomass saving potential in the selected countries (million tons/year)

Country	Type of biomass			
	Fuelwood	Agri-residues	Animal dung	Charcoal
China	51.59	77.21	2.93	0.03
India	69.50	20.88	28.56	0.49
Nepal	3.10	1.23	0.75	0.00
Pakistan	17.51	7.30	8.31	0.00
Philippines	7.61	2.26	—	0.25
Sri Lanka	2.61	0.46	—	—
Vietnam	15.79	3.93	—	0.07
Total	167.72	113.26	40.55	0.85

biomass saving potential in the region, amounting to about 5.5 million tons per annum. Use of biomass for kilns is not common in the Philippines.

The possible substitution of kilns presently in use suggests a total biomass saving potential of approximately 5.97 million tons of fuelwood and 0.14 million tons of ricehusk annually in the selected countries Table 21, Table 22.

4. Conclusions

Domestic cooking is found to be the largest consumer of biomass energy in the rural sector and often in the whole of the country. It is also the sector which uses inefficient, traditional devices and, hence, accounts for a considerable waste of biomass energy. In all the seven countries studied, the total biomass saving potential in domestic cooking is an estimated 292 million tons/year.

In the Industrial Sector, the major biomass energy devices are bakery ovens, boilers, furnaces and kilns. Among them, furnaces and kilns are the largest consumers of biomass energy, consuming about 12.45 and 8.80 million tons of biomass per annum, respectively. The saving potentials of biomass in industrial boilers and bakery ovens are estimated at about 6.56 and 1.53 million tons/year, respectively.

- Large amounts of biomass can be saved by improving the efficiency of biomass energy utilization. The total biomass saving potential through efficiency improvements for the selected Asian countries is an estimated 322 million tons annually.
- Domestic cooking is the single largest component, responsible for about 90% of the total biomass energy consumption in all these countries together. It is also an area which stands out from the rest as the most promising area for efficiency improvements, with potential biomass savings of about 152 million tons of fuelwood and 101 million tons of agricultural residues.
- Furnaces and kilns are the other energy systems which seem to be operating inefficiently,

with a saving potential of 12.45 and 8.80 million tons/year respectively, or 3.86 and 2.73% of the total. Bakery ovens and boilers offer fuelwood saving potential of 1.53 and 6.56 million tons per annum, respectively. The bagasse saving potential in industrial boilers in all the countries total 5.91 million tons/year.

Acknowledgements

The financial support by the Swedish International Development Co-operation Agency (Sida) for this study in the framework of the project "Renewable Energy Technologies in Asia—A Regional Research and Dissemination Programme" is gratefully acknowledged.

References

[1] Abilio AR. Bagasse drying project at Mirpur Khas sugar mills in Pakistan Personal Contacts 1995.
[2] Amur GQ. Assessment of export power options for a sugar mill in Pakistan. M. Eng. Thesis, Asian Institute of Technology, Bangkok 1994.
[3] Amur GQ. Energy efficiency study at a sugar mill in Pakistan. In: Asian Regional Research Program in Energy Environment and Climate (ARRPEEC), Energy Program. Bangkok: Asian Institute of Technology, 1996.
[4] Amur GQ, Bhattacharya SC. Biomass as a Source of Energy in Pakistan. In: Asian Regional Research Program in Energy, Environment and Climate (ARRPEEC), Energy Program. Bangkok: Asian Institute of Technology, 1997.
[5] IFSC. International Forest Service Consultancy. The Use of Wood by the Tobacco Industry in India. Edinburgh, 1987.
[6] Bhattacharya SC. Opportunities for Energy Conservation—Wood Energy for Rural Industries: Thailand, GCP/RAS/111/NET. Bangkok: Food and Agricultural Organization (FAO) of the United Nations, 1986.
[7] Bioenergy Systems Report—Energy from Rice Residues USAID, March 1990.
[8] Boiling Point. Stoves Used for Cooking. In: Water Heating and Space Heating at High Altitude in Nepal—A Case Study in Jumla. RECAST, Nepal, 1993.
[9] Cabrera MI. Energy Program. Bangkok: Asian Institute of Technology, 1997 personal communication.
[10] CAAERP Chinese Academy of Agricultural Engineering Research Planning. Chinese Fuel Saving Cookstoves: A Compendium. FAO, Bangkok, 1993.
[11] CICD (Chemonics International Consulting Division). Improved Cooking Stoves: The Nepal Experience. Report on Seminar Proceedings, Kathmandu, USAID-Nepal Contract No. 367-0158-CO299-00 1991.
[12] ESCAP. Agricultural Biomass for Sustainable Rural Development, Khai, Nguyen Quang, State of the Art of the Utilization of Agricultural Residues and Other Biomass and Identification of Priority Projects in Vietnam. In: Proceedings of the Workshop on Human Resources Development for Utilization of Agricultural Residues as Energy Source, held in China, 14–13 May, 1993.
[13] Energy Synopsis Report Water and Energy Commission Secretariat (WECS), Ministry of Water Resources, Nepal 1994.
[14] FAO. The Use of Wood Fuels in Rural Industries in Asia and Pacific Region, RWEDPA, GCP/RAS/111/NET. Food and Agriculture Organization of the United Nations, Bangkok 1988.
[15] FAO. Status of Wood Energy in Rural Industries in Asia, RWEDPA, GCP/RAS/131/NET, Food and Agriculture Organization of the United Nations, Bangkok 1990.
[16] FAO Sub-Regional Expert Consultation—Improved Cookstove Development Programme in South Asian

Countries, RWEDPA, GCP/RAS/131/NET, Food and Agriculture Organization of the United Nations, Bangkok 1991.

[17] FAO. Indian Improved Cookstoves: A Compendium, RWEDPA, GCP/RAS/131/NET, Food and Agriculture Organization of the United Nations, Bangkok 1993a.

[18] FAO Chinese Fuel Saving Stoves: A Compendium, RWEDPA, GCP/RAS/131/NET, Food and Agriculture Organization of the United Nations, Bangkok 1993b.

[19] FAO. Proceedings of the Regional Expert Consultation on Selection Criteria and Priority Rating for Assistance to Traditional Biomass Energy Using Industries, RWEDP, Food and Agriculture Organization of the United Nations, Bangkok 1997.

[20] Hirun A, Siratanapantra T, Sucharitakul T, Rerkkriangkrai P, Terdtoon P. Energy Conservation for Thailand's Flue-cured Tobacco Industry, Proceedings of the Regional Seminar on Alternative Energy Applications in Agriculture, held at Chiang Mai University, Thailand during 27–29 October, 1986 1986.

[21] Imtiaz A. State of Art of the Utilization of Agricultural Residues and Other Biomass and Identification of the Priority Projects in Pakistan. In: Proceedings of the Regional Workshop on HRD for Utilization of Agriculture Residues as an Energy Source, held in China. ESCAP, 1993. p. 236–48.

[22] Institute of Energy Formulation of Balance of General Energy and Policy of National Energy up to Year 2005, Hanoi, Vietnam 1993.

[23] Joseph S The Baking Industry in Asia: A Review, Status of Wood Energy in Rural Industries in Asia. RWEDP, GCP/RAS/131/NET, Food and Agriculture Organization of the United Nations, Bangkok 1990.

[24] Joseph S. Cookstove Research and Development Issues, Status of Wood Energy in Rural Industries in Asia. RWEDP, GCP/RAS/131/NET, Food and Agriculture Organization of the United Nations, Bangkok 1991.

[25] Khoa TM. Biomass Energy in Vietnam: An Experimental Study on Emissions from Domestic Cookstoves, M.Eng. Thesis, Asian Institute of Technology, Bangkok 1996.

[26] Koopmans A Status and Development Issues of the Brick Industry in Asia. RWEDPA, GCP/RAS/131/NET, Food and Agriculture Organization of the United Nations (FAO), Bangkok, April 1993.

[27] Kumaradasa MA. Technology-wise Biomass Use in Sri Lanka. Asian Regional Research Program in Energy, Environment and Climate (ARRPEEC), Energy Program, Asian Institute of Technology, Bangkok 1996.

[28] Kumaradasa MA(personal communication) 1995.

[29] Lepeleire DeG, Krishna PK, Verhaart , Visser P. A Woodstove Compendium 1981.

[30] Liaoning Institute of Energy Resources. Yingkou China Review of Energy-efficiency Studies in China 1996.

[31] Liadpratom S. A Study of Thermal Energy Conservation in a Canning Food Plant, Master Thesis, Energy Technology Program, School of Energy and Materials, King Mongkut's Institute of Technology, Thonburi, Bangkok, Thailand, p. 192, in Thai, 1989.

[32] MNES Ministry of Non-conventional Energy Sources, 1996–97, Annual Report 1996–97, Govt. of India.

[33] Narang HP. (personal communication) 1996.

[34] Non-Conventional Energy Division (NCED), 1996, Technology-wise Biomass Consumption in Philippines, Asian Regional Research Program in Energy, Environment and Climate (ARRPEEC), Energy Program, Asian Institute of Technology, Bangkok, Govt. of Philippines.

[35] Parashar DC, Narang HP. Sector-wise Biomass Energy Use in India, Asian Regional Research Program in Energy, Environment and Climate (ARRPEEC), Energy Program, Asian Institute of Technology, Bangkok, 1996.

[36] Sharma M. Techno-Environmental Assessment of Biomass as a Source of Energy: The Case of Nepal, M. Eng. Thesis, Asian Institute of Technology, Bangkok, 1995.

[37] Shriram KS Assessment of Energy Management Options in Indian Sugar Industry. M. Eng. Thesis, Asian Institute of Technology, Bangkok, 1995.

[38] Sitthiphong N et al. Energy Conservation in Tobacco-Leaves Curing in Northern Thailand. A Progress Report submitted to ASEAN Working Group on Non-Conventional Energy Research and Government of Australia 1985.

[39] Soponronnarit S, Peanklang K, Tia W. A Study of Energy Profile in a Rice Mill. International Conference on Energy and Environment, 27–30 November, Bangkok 1990.

[40] Tamnathong N. Thermal Energy Analysis in a Sugar Mill, M. Eng. Thesis, Asian Institute of Technology, Bangkok 1986.

[41] Tanawat C. Emission from Biomass Combustion Systems in Thailand, M. Eng. Thesis, Asian Institute of Technology, Bangkok 1996.
[42] Yuan-Bin He, Qing-Yu Jiao (Personal communication) 1995.
[43] UNDP. House Hold Energy Demand Consumption Patterns. In: Pakistan Household Energy Study Survey, Energy Wing. Government of Pakistan, 1993.
[44] UNESCO Consolidation of Information—Cooking Stoves Handbook 1982.
[45] Wibulswas P, Balakrishnan SV, Bhattacharya SC. Energy Analysis of Cogeneration using Bagasse as Fuel. In: Advances in Solar Energy Technology. Oxford: Pergamon, 1987. p. 2988.
[46] Viqar Energy Analysis of Cogeneration in a Sugar Mill in Pakistan, M. Eng. Thesis, Asian Institute of Technology, Bangkok 1988.
[47] NREL. A Study of the Market for Ricehusk to Energy Systems and Equipment. In: The National Renewable Energy Laboratory. US Department of Energy, Golden, Colorado, 1996.
[48] Svenningson J. Study of the use of Fuelwood in Brick Making Industry in Guayaquil, Equador. In: Status of Wood Energy in Rural Industries in Asia. Food and Agriculture Organization of the United Nations (FAO), Bangkok, 1990.
[49] MUCET Estimates. Data on Biomass Energy Consumption in Pakistan. Pakistan: Mehran University College of Engineering and Technology, 1995.
[50] DoE. Department of Energy, Philippines, Personal communication.