A Study of Biomass as a Source of Energy in India

H.P. Narang and D.C. Parashar
National Physical Laboratory, New Delhi
INDIA

S.C. Bhattacharya and P. Abdul Salam
Energy Program
School of Environment, Resources and Development
Asian Institute of Technology
P.O. Box 4, Klong Luang, Pathumthani 12120
THAILAND

ABSTRACT

Biomass is a major source of energy in India. However, as in the case of most developing countries, reliable estimates of biomass energy use in different sectors of the country are not available. An assessment of sectoral biomass energy consumption in India has been presented in this paper. It is estimated that the total biomass consumption for energy was about 321 billion kg or 380 kg/capita/year (103 MTOE or 0.12 TOE/capita/year) in the year 1990-1991; this amounted to 45% of the total primary energy consumption of the country. The share of fuelwood in the traditional energy is about 53%. The household sector is the major end user and consumes 83% of the total biomass energy. The traditional cookstoves are the major end users of biomass energy, and accounted for about 76% of the total consumption.

1. INTRODUCTION

The primary conventional energy consumption of India was 125 million ton oil equivalent (MTOE) during 1990-1991, and increased to 150 MTOE in the year 1994-1995 [1]. Oil and coal are the dominant sources, supplying 61 MTOE (41%) and 54 MTOE (36%) respectively of the total primary conventional energy consumption during 1994-1995. The other sources of energy, natural gas, soft coke, LPG and electricity accounted for 8 MTOE (5%), 0.16 MTOE (0.11%), 4 MTOE (3%), and 22 MTOE (15%), respectively during 1994-1995 [1].

Apart from commercial energy, large quantities of biomass energy are also consumed annually. The main sources of biomass energy are fuelwood, crop residues, dung, charcoal, and biogas. Reliable estimates of traditional energy consumption are normally not available. Considering the importance of assessing biomass energy use for energy planning purposes, a regional study was carried out in a number of Asian countries within the framework of a project funded by the Swedish International Development Cooperation Agency (Sida). This paper presents the results of the study carried out on biomass energy use in India.

2. BIOMASS ENERGY SOURCES IN INDIA

2.1 Fuelwood

The main sources of fuelwood in India are state-owned forests and private farmlands. Apart from these, fuelwood is also obtained from trees and shrubs available on other categories of land such as orchards and groves, village common lands and homestead in rural areas. The sustainable production of the forest has been estimated at 0.7 m^3 per 10,000 m^2 which is very low when compared with the world average of 2.1 m^3 per 10,000 m^2. The average growing stock is 65 m^3 per 10,000 m^2 as against the world average of 110 m^3 per 10,000 m^2. The total availability of fuelwood from forests and private farmlands was 58 billion kg in the year 1996 [1].

The fuelwood consumption, as reported by Reddy [2], was 150 million m^3 (112 billion kg) during the year 1990. According to Parashar and Narang [3], the total fuelwood consumption in India was 138 billion kg in the year 1990-1991.

Goel and Behl [4] reported that the annual fuel wood consumption in early 1990s has been estimated to be about 253 million m^3.

Das [5] estimated that annual fuelwood consumption was in the range of 120 billion kg to 130 billion kg.

Fuelwood production has been reported to be about 235 billion kg in 1994, and is projected to increase to 255 billion kg by the year 2010, as shown in Table 1 [6]. In addition, the requirement of fuelwood in the year 1994 was 173 billion kg and is projected to increase to about 225 billion kg by the year 2010. The total national data implies that there is no fuelwood and biomass energy shortage in India overall, however, this gives little information about fuelwood situation at the local levels.

Table 1. Fuelwood production in India in 1994-2010 [6].

Fuelwood sources	1994			2010		
	billion kg	percentage	MTOE	billion kg	percentage	thousand TOE
Natural forests	35.80	15.22	12.61	32.90	12.87	11.60
Natural forests (wood wastes)	19.00	8.08	6.69	17.28	6.76	6.08
Plantation	49.90	21.22	17.56	65.40	25.58	23.03
Other wooded lands	5.15	2.19	1.80	2.00	0.78	0.70
Agriculture areas	125.32	53.29	44.13	138.13	54.01	48.64
Total	235.17	100.00	82.79	255.71	100.00	90.05

2.2 Agricultural Residues

Crop residues account for a large share of biomass energy use in India. A study of the National Productivity Council [7] estimated that the total production of agricultural residues was about 320 billion kg in 1985-1986.

Table 2 shows the estimated amounts of crop residues produced in India in 1990-1991 [1] and in 1994 [6]. The table also shows the projected residue production in the year 2010 [6]. Teddy [1] estimated the total residue produced during 1990-1991 to be 238 billion kg. Koopmans' [6] estimates of the total residue production in 1994 and 2010 are 602 billion kg and 890 billion kg, respectively. Assuming only 50% of the processing residues to be available for energy use, Koopmans [6] estimated the residue available for energy use in 1994 and 2010 to be equivalent to 27.3 MTOE and 42 MTOE, respectively.

Field Based Residues

Teddy [1] estimated that the production of wheat straw, millet stalks, cotton stalks and jute stalks in 1990-1991 was 73.5 billion kg, 11.4 billion kg, 22.3 billion kg, and 3.1 billion kg, respectively. Table 2 also shows the field based residues as estimated by Koopmans [6].

Processing Based Residues

Teddy [1] estimated the production of rice husk, maize cob, coconut shells, coconut husks, groundnut husks and bagasse in 1990-1991 as shown in Table 2.

A number of other processing based residues such as distillery effluents, pressmud and fruit and vegetable processing residues are also produced in significant quantities annually [8].

Table 2. Estimated amount of crop residues produced in India [1, 6].

Residues	Billion kg		
	1991 [1]	1994 [6]	2010 [6]
Field based residues			
Rice straw	-	214.35	284.99
Wheat straw	73.50	103.48	159.98
Millet stalks	11.40	19.42	17.77
Maize stalks	-	18.98	29.07
Cassava stalks	-	0.36	0.40
Cotton stalks	22.30	19.39	30.79
Soyabeans (straw+pods)	-	12.87	34.87
Jute stalks	3.10	4.58	1.21
Sugar cane tops	-	68.12	117.97
Cocoa pods	-	0.01	0.01
Subtotal	**110.30**	**461.55**	**677.06**
Processing based residues			
Rice husk	37.10	32.57	43.31
Rice bran	-	10.13	13.46
Maize cob	2.70	2.59	3.97
Maize husks	-	1.90	2.91
Coconut shells	1.30	0.94	1.50
Coconut husks	4.00	3.27	5.22
Groundnut husks	2.50	3.94	4.80
Groundnut straw	-	19.00	23.16
Sugar cane bagasse	80.40	65.84	114.04
Coffee husk	-	0.36	0.28
Subtotal	**126.40**	**140.53**	**212.64**
Total	**238.30**	**602.08**	**889.70**

2.3 Energy Plantation

Energy plantation program was initiated by the Ministry of Non-Conventional Energy Sources mainly to test the performance of fast growing fuelwood species and to screen the most promising species for plantation under a given set of agro-climatic conditions. The plantations are being undertaken on problem soils like saline/alkaline soils, water logged soils, ravine lands, shifting sand dunes, etc. As the purpose of energy plantation is to produce energy rather than industrial wood, the species are selected to achieve high biomass yield. The ultimate energy potential will depend upon the waste lands that could be available for energy plantation. A MNES study has estimated the total availability of such land at 626 000 km^2. The fuelwood yields on such plantations will depend upon the plant species, type of soil, rainfall and various inputs provided to the plantation amongst many other factors. The MNES study assumes a yield of 1.6 kg per m^2 giving potential to provide about one trillion kg of wood per year corresponding to total energy potential of 357 MTOE.

2.4 Animal and other Organic Wastes

Animal Waste

It is estimated that 84% of the rural household energy demand in India is for cooking and about 15% of this is met by dung cakes [3].

The quantity of waste produced per animal per day varies depending on various factors such as body size, kind of feed, level of nutrition, etc. As reported by Teddy [1], the total population of cattle and buffaloes in the country was 196 million and 77 million heads, respectively in 1996. The total production of cattle and buffalo dung has been estimated to be 616 billion kg on wet basis.

Jossy [9] compiled the values of total dry matter production per day for different animals as reported by various researchers. As substantial differences in the reported values were found to exist, suitable values were also selected for estimating annual dry dung production.

Using the livestock population figures of 1990 [10], the average dry matter production per animal per day [9] and the bio-gas yield per kg of dry matter [8], the estimates of total dry dung production and the theoretical potential of biogas yield per annum are presented in Table 3.

Table 3. Estimates of dung production (dry matter basis) and the total potential of biogas yield per annum for the base year 1990-1991.

Animal	Population (million)	Dung production per head per day (kg)	Annual dung production (billion kg)	Gas Yield	
				m^3/kg dry matter	Total potential (billion m^3)
Cattle	192	2.86	200.4	0.20	40.08
Buffaloes	70	2.52	64.4	0.20	12.88
Goats	110	0.55	22.1	0.25	5.53
Sheep	44	0.33	5.3	0.25	1.33
Pigs	10	0.66	2.4	0.56	1.34
Total			294.6		61.16

Assuming a 60% collection rate for dung, the amount of recoverable dry animal waste and technical potential of biogas production are estimated at 177 billion kg and 36.7 billion m^3, respectively. The 177 billion kg of recoverable animal waste (on dry matter basis) has a total energy potential of 42.1 MTOE and assuming an average calorific value of biogas at 20 930 kJ/m^3, the 36.7 billion m^3 of biogas has an exploitable energy potential of 18.4 MTOE.

Human Waste

Estimates of the total and exploitable energy potential from human waste have been made as shown in Table 4. As human waste is 100% recoverable, its exploitable energy potential can be taken as the same as the total potential, i.e., 6.19 MTOE per year.

Municipal Solid Waste

The combustible components of municipal solid wastes (MSW) can be incinerated and the heat released can be recovered for good utilization. Alternatively, it can be used for biogas generation. It is estimated that 0.4 kg per capita per day of waste is generated in Indian cities. MSW from 10% of the total population of 846 million (March 1991 Census) living in principal urban areas can be considered for energy recovery. It is estimated that 12.35 billion kg of MSW can be utilized for energy per year. A Jardine and Fleming Research Study [11] estimates that 150 kg of MSW can produce 14 m^3 biogas having methane content of 55% to 65% and 45 kg of organic matter; based on this, the recoverable MSW can produce about 1.15 billion m^3 of biogas equivalent to about 0.60 MTOE of energy and 3.7 million kg of organic manure.

2.5 Overall Energy Potential

Parashar and Narang [3] estimated the total energy potential of different biomass sources in India as shown in Table 5.

While, presently, field based and processing based residues and animal wastes are being significantly exploited, significant potential exists for biomass production from energy plantations on 626 000 km^2 of wasteland.

Table 4. Estimates of total energy potential from human waste.

Item	Value	Ref.
Population, million	846	Europa World Book [10]
Dry matter production, kg/head/day	0.09	Jossy [9]
Total dry matter per year, billion kg	28	-
Biogas yield, m^3 per kg dry matter	0.45	Jain [8]
Total biogas potential, billion m^3/year	12.60	-
Calorific value, kJ/m^3	20,930	-
Energy potential, MTOE/year	6.19	-

Table 5. Estimates of total and exploitable energy potential from different biomass source.

Biomass source	Estimated total energy potential in 1990-1991 (MTOE)
Field based residues	27.38
Processing based residues	15.48
Energy plantation	357.14
Animal waste	42.14
Human waste	6.19
MSW	0.60
Total	448.93

2.6 Sectoral Biomass Consumption in India

Biomass is used as energy source in household, commercial and industrial sectors.

Household Sector

A large scale domestic fuel survey carried out by the National Council for Applied Economic Research (NCAER) in 1978-1979 [12] covering 13,010 households spread over 18 states, estimated the actual per capita consumption of various biofuels in rural and urban residences as shown in Table 6. More recently, data on rural energy surveys conducted during 1985-1992 has been compiled to create rural energy database [13]. In this, the low, high and average estimates of the consumption of different biofuels have been presented for the rural areas. In this paper, biofuel consumption in the residential sector, for the year 1990, has been estimated based on per capita consumption values given in Table 6 and the rural and urban population in the year 1990. The results as presented in Table 7, show that about 124.5 billion kg of fuelwood, 38.4 billion kg of crop residues, 91.6 billion kg dung, and 950 million kg of charcoal were consumed in the household sector to meet the demand for cooking, water heating, etc. during 1990-1991.

Table 6. Per capita consumption of biofuels for energy in residential sector [12].

Fuel type	Annual norm, kg/capita	
	Rural	Urban
Fuelwood	158.0	116.4
Crop residue	58.8	5.6
Dung	133.0	35.6
Charcoal	0.2	3.8

Table 7. Consumption of biofuels for energy in residential sector during 1990-1991 (billion kg).

Fuel type	Rural	Urban	Total
Fuelwood	100.00	24.50	124.50
Crop residue	37.20	1.20	38.40
Dung	84.10	7.50	91.60
Charcoal	0.15	0.80	0.95
Total biofuels	221.45	34.00	255.45

Population in 1990: Rural, 633 million; urban, 211 million.

Commercial and Industrial Sectors

Biofuels are also used as energy source in rural industries and services, whereas in urban areas they are used in service establishments. In industry, it is common to use rice husk in rice mills, bagasse in sugar industry, coconut shells in copra drying, lime and brick kilns, etc. Bagasse is primarily used as a fuel to provide process steam for sugar manufacturing. About 87% of the bagasse is used within the mills to produce process steam and electricity for in-house use, with the remainder considered as surplus [14]. In the year 1990-1991, about 51% of the total cane production was used in sugar mills. Thus, out of a total of 80.4 billion kg of bagasse produced [1], 35.67 billion kg was used as fuel in the sugar mills. About 10 billion kg of rick husk and groundnut shells were used as industrial fuel, making a total of 45.67 billion kg of processing based residues used for energy in the industrial units almost doubled during this period.

Estimates for the consumption of fuelwood in industrial units are also available for the year 1983-1984 [15] and 1989-1990 [16]. The estimates indicate that fuelwood consumption in industrial units almost doubled during this period.

Estimates of annual consumption of biofuels in the commercial establishments for the year 1978-1979 [12] are presented in Table 8. It appears reasonable to assume that biofuel consumption in commercial establishments doubled during the period 1978-1979 to 1990-1991. Estimates of the total consumption of biofuels in industry and commercial establishments during 1990-1991 are presented in Table 9.

Table 8. Consumption of biofuels in commercial establishments (billion kg) [3].

Fuel type	Rural	Urban	Total 1978-1979	Estimated 1990-1991
Fuelwood	3.15	1.13	4.28	8.56
Crop residue	0.36	0.20	0.56	1.12
Dung	2.48	0.02	2.50	5.00
Charcoal	0.46	0.24	0.70	1.40
Total biofuels	6.45	1.59	8.04	16.08

Table 9. Total consumption of biofuels in the commercial and industrial sectors in 1990-1991 (billion kg).

Fuel type	Consumption in establishments	Consumption in industry	Total consumption
Fuelwood	8.56	4.94	13.50
Crop residues	1.12	44.55	46.00
Dung	5.00	-	5.00
Charcoal	1.40	-	1.40
Total biofuels	16.08	49.49	65.67

2.7 Biomass Energy Consumption in India

The biomass energy consumption in the year 1990-1991 has been summarized in Table 10. The total biomass energy consumed in the year 1990-1991 was 103.4 MTOE. The shares of biofuels in the total biomass energy were, fuelwood 53%, bagasse 7%, other crop residues 14%, dung 24%, and charcoal 1.5%. The share of biomas in the total energy consumption of the country during the same year was 45%, as shown in Table 11. The household sector is the major end user of biomass energy and utilized 85.7 MTOE (83%) followed by commercial and industrial sectors which consumed 17.7 MTOE (17%).

Table 10. Biomass energy consumption in India in 1990-1991 (billion kg).

Biofuels	Consumptions	MTOE	%
Fuelwood	138.00	55.06	53.3
Bagasse	35.67	7.06	6.8
Other crop residues	48.40	14.71	14.2
Dung	96.60	25.00	24.2
Charcoal	2.35	1.52	1.5
Total	**321.02**	**103.85**	**100.00**

Table 11. Share of biomass energy in total energy demand of India in 1990-1991.

Description	MTOE	%
Primary energy consumption from biomass	103.35	45.3
Primary energy consumption from conventional sources	124.90	54.7
Total primary energy consumption	228.25	100.00

3 BIOMASS ENERGY CONSUMPTION IN END-USE TECHNOLOGIES

A large part of the energy consumed by both rural and urban population in India is in the form of fuelwood, agricultural residues and cattle dung. These biomass fuels are used in various end-use devices, for example cookstoves in the residential sector and boilers, furnaces, kilns, ovens, etc. in the industrial sector.

3.1 Biomass Use in the Household Sector

Cookstoves

Biomass energy consumed in the household sector of India is about 83%. About 125 billion kg or 150 kg per capita of fuelwood is estimated to have been used for combustion in the year 1990 [17]. The fuelwood consumed in the residential sector is used for cooking or water heating using the traditional or improved cookstoves. Over 17 million improved cookstoves were in use in the year 1994-1995, resulting in a saving of about 1.2 billion kg of fuelwood equivalent [18].

The traditional cookstoves are normally constructed from mud, and in some areas the combustion chamber of the stove lie in the ground with a fuel feed opening at the top. The thermal efficiency (ratio of useful heat obtained to the total heat supplied to the cookstove by burning biofuels) of the traditional cookstove is about 13% [19].

In addition to 125 billion kg of fuelwood, about 77 billion kg of dung and 38 billion kg of crop residues were also utilized in traditional and improved cookstoves in the year 1990-1991.

Biogas Plants

There were about 1.4 million family type biogas plants set up in the country up to 1990-1991, and generated gas equivalent of about 4.5 billion kg of fuelwood [1, 20]. Of the 91.6 billion kg of animal dung consumed in the residential sector in the year 1990-1991, about 14.6 billion kg were used in the biogas plants.

3.2 Biomass Use in the Industrial and Commercial Devices

There are about 115,000 industrial units in the country which together use about 5 billion kg of fuelwood annually [16]. In addition, 8.5 billion kg of fuelwood is estimated to be used in rural and urban commercial establishments [3]. A total of 13.5 billion kg of fuelwood consumed in the industrial and commercial sectors is utilized in different end-use devices.

Furnaces and Kilns

Fuelwood is mostly used in the manufacture of some construction materials such as bricks, tiles and lime, and in the preparation of jaggery (gur) in the rural areas using traditional types of furnaces and kilns. Some institutional kitchens, restaurants and canteens in some rural and semi-urban areas also use fuelwood for energy. The consumption of fuelwood has been estimated to be 8.25 billion kg [2].

Most of the other processing based residues like rice husk and groundnut shells are used in furnaces and kilns used for brick and lime making, in rice mills for parboiling rice, for copra

making and for commercial baking, cooking, etc. The total consumption is estimated to be 10 billion kg [21].

There is no industrial use of dung and most of the 5 billion kg, estimated to have been consumed by the establishments, was used in furnaces for baking and cooking [21].

Commercial Boilers

Some of the small industries, particularly in the regions where there is a coal shortage, fuelwood is still used in the boilers for heating and processing purposes. The annual consumption has been estimated to be 1.75 billion kg [21].

Commercial Ovens

Some of the commercial ovens such as those used for baking, tobacco curing, drying of spices, wood, paper and leather use fuelwood. The total consumption in this field has been taken as 3.5 billion kg [21].

Sugar Mill Boilers

There are 400 sugar mills having 1,100 boilers utilizing bagasse as fuel for generating steam. Capacity of the boilers range from 5000 kg/hour to 50 000 kg/hour of steam. Nearly 35.7 billion kg bagasse is used by the sugar mills themselves for firing these boilers.

3.3 Summary of Biomass Consumption by End-use Technologies

Biomass consumption in different end-use devices is shown in Table 12. It can be observed that a large quantity of biomass was consumed in the traditional devices during the year 1990-1991. The traditional cookstoves are in common use in most of the households and consumed about 120 billion kg of fuelwood, with about 5 billion kg consumed in the improved cookstoves. Only 1.54 billion kg of crop residues and 3.1 billion kg of dung were consumed in the improved cookstoves and the remaining was utilized in the traditional devices.

In the commercial and industrial sectors, about 13.5 billion kg of fuelwood, 45.7 billion kg of crop residues and 5 billion kg of animal wastes were consumed. Furnaces and kilns consumed 8.25 billion kg of fuelwood, while commercial boilers and ovens utilized 1.75 billion kg and 3.5 billion kg of fuelwood, respectively. In addition, 35.7 billion kg of crop residues (mostly bagasse) was consumed by the sugar mill boilers, and 10 billion kg of crop residues were used in furnaces and kilns.

4. CONCLUSIONS

The total biomass energy consumption in India in the year 1990-1991 was 321 billion kg (380 kg/capita/year) or 103 MTOE (0.12 TOE/capita/year) accounting to 45% of total primary energy consumption in the country. The contribution of fuelwood, bagasse, other crop residues,

Table 12. Technology-wise biomass consumption as energy in India in 1990.

Biomass	Industrial and commercial sectors	M.C*	billion kg/year	Residential sector	M.C	billion kg/year
Wood	Furnaces/kilns		8.25	Cookstoves		
	Commercial boilers	15	1.75	-Traditional	15	119.50
				-Improved		5.00
	Commercial ovens		3.50			
	Total		**13.50**	**Total**		**124.50**
Crop residues	Boilers (bagasse)	50	35.67	Cookstoves		
	Furnaces/kilns	15	10.00	-Traditional	15	36.86
				-Improved		1.54
	Total		**45.67**	**Total**		**38.40**
Charcoal	Establishments	3-5	1.40	Charcoal stoves	3-5	0.95
	Total		**1.40**	**Total**		**0.95**
Animal wastes	Furnaces/ovens	15	5.00	Cookstoves		
				- Traditional		73.90
				- Improved	15	3.10
				Biogas plants		14.60
	Total		**5.00**	**Total**		**91.60**

Note: *percentage of moisture content (M.C) on wet basis.

animal waste, and charcoal was 55 MTOE (53%), 7 MTOE (7%), 15 MTOE (14%), 25 MTOE (24%), and 1.5 MTOE (1.5%), respectively.

The household sector accounted for about 83% of the total biomass energy consumed in 1990-1991, while the remaining was consumed in the commercial and industrial sector.

Cookstoves are the major biomass energy end use devices. About 125 billion kg (150 kg/capita/year) of fuelwood is utilized in the cookstoves, along with 38 billion kg (45 kg/capita/year) of crop residues and 77 billion kg (90 kg/capita/year) of animal dung. Biogas plants use a substantial amount (14.6 billion kg) of animal dung.

5. ACKNOWLEDGMENTS

The authors would like to thank the Swedish International Development Cooperation Agency (Sida) for financial support provided for this work under the framework of the Asian Regional Research Programme in Energy, Environment and Climate (ARRPEEC).

6. REFERENCES

1. Teddy. 1997. Tata Energy Research Institute. New Delhi, India.
2. Reddy, B.S. 1994. Biomass energy for India: An overview. *Energy Conversion Management* 35 (4): 341-361.
3. Parashar, D.C. and Narang, H.P. 1996. Sectoral Biomass Consumption in India. A Country Report prepared by Indian country experts of the project, A Study on Biomass as a Source of Energy and Technical Options for Green House Gas Emission Reduction of the Asian Regional Research Program in Energy, Environment, and Climate (ARRPEEC), Asian Institute of Technology, Bangkok, Thailand.
4. Goel, V.L and Behl, H.B. 1996. Fuelwood quantity of promising tree species for alkaline soil sites in relation to tree age. *Biomass and Biomass Energy* 10 (1): 57-61.
5. Das, R.C. 1988. Energy from biomass: Prospects and problems in India. *Energy Environment Monitor* 4 (2): 91.
6. Koopmans, A. 1998. Biomass Energy Resources for Power and Energy. Regional Wood Energy Development Program (RWEDP), FAO-Bangkok. Paper presented at the Expert Consultation on Options for Dendro-Power in Asia, in Manilla, 1-3 April 1998.
7. National Productivity Council (NPC). 1987. *Study Report: Improvement of Agricultural Residues and Agroindustrial By-products Utilization.* New Delhi: Ministry of Non-conventional Energy Sources, Government of India.
8. Jain, M.C. 1993. Bioconversion of organic wastes for fuel and manure. *Fertilizer News* 38 (4): 55-61.
9. Jossy, M.T. 1994. A Study of Greenhouse Gases Emission from Agricultural Residues in Asia, M. Eng. Thesis No. ET-94-15, Asian Institute of Technology, Bangkok, Thailand.
10. Year Book (1994), The Europa World Year Book.
11. Times of India. November 1, 1994.
12. Natajaran. 1985. *Domestic Fuel Survey with Special Reference to Kerosene.* New Delhi: National Council for Applied Economic Research (NCAER).
13. Joshi, V.; Sinha, C.S.; Karuppasamy, M.; Srivasatava, K.K.; and Singh, P.B. 1992. Rural Energy Data Base, 1992. Final Report, submitted to the MNES, Government of India. New Delhi.
14. Singh, G.B. and Solomon, S. Alternative products from sugarcane: industrial and agricultural uses. *Sugarcane: Agro-industrial Alternatives.* New Delhi: Oxford and IBH Publishing Co., Pvt., Ltd.
15. ASI. 1990. *Annual Survey of Industries (1983-84).* New Delhi: Department of Statistics, Government of India.
16. ASI. 1995. *Annual Survey of Industries (1989-90).* New Delhi: Department of Statistics, Government of India.
17. Narang, H.P. 1995. In *Proceedings of the Asian Workshop and Training Course on Measurement Techniques and Inventories of Greenhouse Gases.* 30 October - 4 November 1995. New Delhi, India.
18. MNES. 1995. Annual Report (1994-95), Ministry of Non-conventional Energy Sources Government of India.
19. Rajpal, P.S.; Shishodia, K.H.; and Sekhon, G.S. 1994. Energy efficient design of a cookstove. *Energy Sources* 16: 387-399.

20. MNES. 1994. Annual Report (1993-94), Ministry of Non-conventional Energy Sources Government of India.
21. Parashar, D.C. and Narang, H.P. 1996. Technology-wise biomass consumption in India. A Country Report prepared by Indian country experts of the project, A Study on Biomass as a Source of Energy and Technical Options for Greenhouse Gas Emission Reduction of the Asian Regional Research Program in Energy, Environment, and Climate (ARRPEEC), Asian Institute of Technology, Bangkok, Thailand.