Fuelwood Fired Cookstoves in Sri Lanka and Related Issues

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Abstract

The improved cookstove (ICS) development and dissemination programmes conducted in the country are reviewed and the current utilization patterns of different cookstoves are estimated. Performance characteristics and emission factors of most commonly used stove categories are presented. Environmental and health implication of domestic cooking are discussed. Impacts of dissemination of ICSs, in terms of fuelwood savings and emission reductions are estimated. The results indicate that only 12% of the fuelwood used for cooking in the domestic sector consumed in ICSs and around 41% of fuelwood could be saved by dissemination of ICSs. This would lead to a considerable reduction in the emissions generated from fuelwood use in domestic cooking.

1. Background

1.1 Country Data

In 1997 total population of Sri Lanka was estimated to be 18.6 million and about 79% live in the rural areas. The current estimate of annual population growth rate is 1.2% and the population is expected to stabilize at around 25 million by 2020 (Statistical Abstract 1997). This shows a 40% increase of population than the present. The average size of a family in Sri Lanka is estimated as 4.6. The total land area of the country is 6.5 Mha. About 27% of the land area is under forest cover and 4.5% of the land is under water. Agricultural land including homesteads is about 57%.

The energy sector in Sri Lanka is dominated by bio-energy, and especially by fuelwood. The total annual primary energy supplied in Sri Lanka during year 1998 was about 326 PJ (or 7786 thousand TOE). This comprises of 51.1% biomass, 12.1% hydro electricity and 36.8% petroleum. The final energy consumption was amounted to about 284 PJ (or 6778 thousand TOE), 18.8 % of which was consumed by industrial sector, 24.6% by transport sector and 56.6% by household & commercial sectors (ECF 2000).

Figure 1: Energy Supply by Source

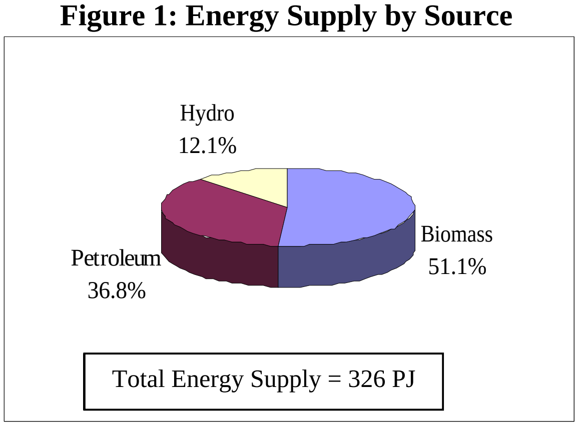
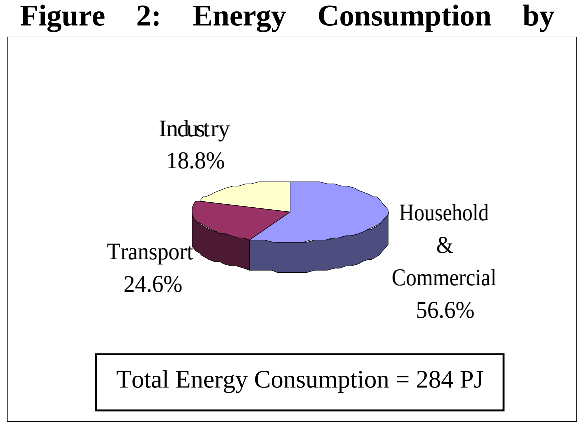


Figure 2: Energy Consumption by



1.2 Biomass Energy

The major share of 84.2% of biomass energy is used by domestic and commercial sectors. The industrial sector (including the plantation industries) consumes the balance. Nearly 90% of the population of Sri Lanka depend on fuel-wood and other forms of biomass for their daily cooking. Thus the major biomass consuming device category is the cookstoves in the domestic sector.

Therefore biomass fuels are of crucial importance, especially for rural people who do not have access to other energy sources. Fuel-wood is also the main thermal energy source for many industries including Agro (Tea, Rubber, Coconut), Manufacturing (brick, tile, lime) and hotels & bakeries. In 1998 the estimated consumption of fuel-wood is 10229 kt and consumption of agro-residues is 313 kt including sugar cane baggase (ECF 2000). Consumption of fuel-wood by sectors in 1998 are given in Table 1.

Table 1: Composition of Fuel-Wood by Sectors

Sector		Consumption (kt)	Sub Total (kt)
Agro Industry	Coconut Processing	125	781 (7.6%)
	Rubber Processing	96	
	Tea Processing	560	
Manufacturing Industry	Brick	575	841 (8.2%)
	Tiles	151	
	Lime	115	
Household	Fuel wood for Cooking	8327	8327 (81.4%)
Commercial Sector	Bakeries, Hotels	279	279 (2.7%)
Charcoal Production	Fuel wood for Charcoal Production	1	1
Total			10,229

Source: ECF (2000)

Supply of biomass mainly comes from fuel-wood and crop residues from natural forests, home gardens, coconut and rubber plantations and other agricultural lands. However some of these are not sustainable, as an example supplies from rubber plantations may decline in the long term because of converting rubber plantations into other land uses. Estimated percentages of sources of bio-energy supply are given in Table 2.

Table 2: Estimated Supply of Biomass by Source

Source of Supply	Amount (%)
Home gardens	26
Coconut	19
Crop lands	19
Natural forest	7
Rubber wood	7
Forest plantation	4
Processing residues	3
Others	14

Source: FSMP (1995)

1.3 Future demand and supply of bio-energy

The main factors which determine the demand for fuelwood by the household sector are population and household growth rate, changes in average household size, rate of urbanization, technological changes resulting in improved energy efficiency, changes in real income, and the availability and relative prices of substitutes. According to the prediction of Forestry Sector Master Plan (FSMP 1995), the consumption of bio energy will grow only very slowly, because of the declining population growth rate, reduced availability of fuelwood, fuel substitution, and improved energy efficiency. In about 2015, the growth is projected to start stagnating and after 2020 the overall consumption of bio-energy is expected to start declining very slowly. Bio-energy consumption in industrial and commercial sectors is projected to decline slowly. The reduction will be mainly due to improved efficiency and technological change, especially in tea industry.

Bio-energy will be sustainably available as wood and crop residues from home gardens, coconut and rubber plantations and other agricultural lands. However, supplies from sources such as rubber plantations may decline in the long term because of converting rubber plantation into other land uses. Natural forests will also provide fuelwood sustainably. Other less important sources of bio-energy include processing residues from saw-milling industry.

In the recent past, Sri Lanka has faced a problem of declining its forest cover due to the unsustainable extraction of wood, clearing of forest for various development programs, clearing of land for chena-cultivation and encroachment due to population rise etc. There will be an increase in the agricultural land by approximately 5% during next 10-year period, which is as a result of increase in home gardens and sparsely used croplands (FSMP 1995). The average rate of deforestation during the above period is approximately 17.4 thousand ha/yr, which is a decrease in comparison with the corresponding amounts of 26.7 during 1980-90 and 21.38 during 1990-95. During the period 1997 - 2010, the forest plantation cutting rate is predicted as 1.8 thousand ha/yr. However the afforestation rate is only 2.3 thousand ha/yr. Therefore the area under forests in Sri Lanka continues to decrease at a net rate of 16.9 thousand ha/yr on average during this period. Note that, as given in Table 2, supply of biomass mainly come from home gardens and agricultural lands; contribution from natural forests is just 7%. At present, there is no fuelwood crisis at the national level. Number of studies also indicates that no serious crisis is likely to be emerged in the near future (FSMP 1995). However in several localities the traditional fuelwood sources have been depleted, and the result has been adverse environmental impacts and local difficulties in meeting the basic energy needs sustainably.

1.4 Fuels for Cooking

Main source of energy for cooking in domestic sector is fuelwood. In addition, LPG and limited amount of biomass residues, kerosene and electricity are also used for cooking. With the urbanization, there has been a significant trend of switching from fuelwood to other sources, especially to LPG in urban and suburban areas. For example, between 1981 and 1991 the consumption of LPG increased tenfold and at present there is a 10% annual increase of LPG use in domestic sector. In 1998, the consumption of LPG in domestic sector was 86 Mt, which contributed to approximately 12% of the energy requirement for cooking.

Kerosene is mainly used for lighting application in rural areas and small percentage is used for cooking application. Prior to marketing of LPG in the country, considerable amount of kerosene was used for cooking. With the availability of LPG, the use of kerosene for cooking has been decreased. But as a result of the recent price hikes of LPG in the country, people are looking for alternative energy sources, such as fuelwood and kerosene. Therefore these trends should be taken into account in predicting future status of fuelwood use for household cooking and resulting impacts.

1.5 Biomass Energy Conversion Technologies and Devices - Current Status

At present, a number of cookstove designs, both traditional cookstoves (TCS) and improved cookstoves (ICS), are in use in the domestic sector of the country. Most widely used TCSs are the three-stone stove and semi-enclosed mud stove ("Sinhala Lipa", similar to U-Chulah). The two-pot "Anagi-2" stove is the only popular ICS design, in spite of different ICS designs introduced through number of ICS development and dissemination programmes launched by various governmental and non-governmental organizations since late seventies. According to a recent study, the percentage shares of fuelwood consumed in the above three categories of stoves are predicted as 60.4% in three-stone cook-stoves, 27.4% in semi-enclosed stoves and 12.2% in ICS (Perera et al. 2000).

The main industries which use biomass as a source of energy includes Agro (tea, rubber, coconut, sugar, etc.), manufacturing (brick, tile, lime, etc.) and commercial concerns such as bakeries, hotels & eating houses. Further, there are number of small scale industries which use bio-energy, such as pottery, ceramic, chemical, metal, leather, textile, soap, road tarring, distilleries, crop & fish drying, laundries, paddy parboiling, etc.

The tea processing industry is the largest industrial consumer of biomass. It uses wood fired furnaces for drying (and weathering) of tea. The coconut industry utilizes fuelwood furnaces (45%), coconut shell fired copra kiln (40%) and fuelwood boilers (12%) and carbonization gas fired furnaces (3%) to meet its energy requirements. The rubber processing industry employs fuelwood furnaces (80%) and fuelwood boilers (20%). The tobacco industry uses fuelwood barns (80%) and paddy husk fired barns (20%). Bagasse fired boilers are available only in the sugar industry. Brick, tile, lime, pottery and bakeries use fuelwood kilns for their production processes. The distilleries use fuelwood furnaces (80%) and paddy husk fired boilers (20%) in the manufacturing process. Paddy processing industry utilizes paddy husk fired boilers for parboiling operation (Kumaradasa et al. 1997).

The most of the existing biomass energy technologies/devices in the country described above are traditional and therefore inefficient and resulting in environment & health problems in addition to the wastage of energy. Therefore there is a considerable potential for biomass conservation and mitigation of greenhouse gas (GHG) and other pollutants emission through efficiency improvements by deployment of modern biomass energy technologies. There is a great interest and demand for improvements of conversion efficiency but lack of funding, expertise and institutional support limit the implementation of such improvements. Number of institutes are actively involved with different aspects of biomass energy, such as research & development of conversion technologies, case studies, country studies, feasibility studies, resource assessments and country-wide energy plantation programme.

This paper concentrates on cookstoves, the major biomass consuming device, and presents the historical development of cookstoves in the country, present status of the technology, performance and fuelwood consumption, and other related issues including the emissions, the potential for saving of fuelwood through efficiency improvements and their impacts.

2. Global View of Cookstove Developments

In the early ages, cooking was done over an open-fire with fuelwood arranged in a pyramid configuration. Open-fire arrangement has many shortcomings including diffusion of heat during windy condition, difficulty of control over the fire, exposure to heat and smoke, fire hazard, etc., besides its very low cooking efficiency. Development of other cookstoves to create a shield-fire became a necessity with the evolution of pots of various shapes and sizes. The simplest and most common form of shield-fire was the three-stone stove. This arrangement allowed the cooking pot to rest firmly on it, partly saved the fire from wind effects and slightly improved cooking efficiency. Yet the three-stone cookstove had similar drawbacks as the open-fire.

Subsequently, the three-stone configuration was changed to a U-shaped semi-enclosed mud stove (or mud/stone stove) with an opening in the front for fuel feeding and combustion air entry. Later a number of modifications was made by the users in light of their own experiences. One of these innovations was the addition of three small humps at the top rim of the enclosure, which acted as a pot rest, induction point of secondary air needed for better combustion of volatile matter and for the exhaust gas exit. Another major modification occurred in the setup was the inclusion of additional pothole enclosures, which are connected to each other by a tunnel. These evolutions improved the cooking efficiency substantially but health and other hazards remained. Despite human evolution and the developments which have taken place in stoves and fuels, at present most of the people live in developing countries still largely employing the three-stone or the U-shaped mud stove for cooking using traditional sources of energy such as fuelwood and other biomass.

In 1950s, improved cookstoves development programmes (ICPs) started in number of developing countries, as examples in India (Raju 1957), Egypt (Theodorovic 1954) and Indonesia (Singer 1961). These programmes involved technical improvements in cookstoves such as introduction of multi-pot stoves, chimney, adjustable dampers, etc., and measurements of cookstove efficiencies. During the period 1950s to 1970s, a series of attempts were taken by governmental and non-governmental organizations to introduce new stove designs, but none of these achieve any significant impact.

The second phase of ICPs started in 1970s when the oil crisis brought energy issues and related environmental concerns to the forefront. Extensive research and development activities were carried out, especially on the thermodynamics, heat transfer and aerodynamics aspects of combustion in small enclosures. As a result a sound engineering base on cookstoves was established, and more systematic design and testing procedure were developed. It was suggested that large number of households were using the traditional three-stone model with overall efficiency of less than 10%. As the efficiencies of ICS models achieved nearly 30% under laboratory conditions, a fuelwood saving potential of more than 70% was anticipated. Encouraged by these figures a large variety of ICS models were developed, especially by research organizations in many developing as well as developed countries. Various international donors were involved with these development and dissemination programmes. In spite of these extensive works, impact of ICPs during the second phase proved to be not very successful. Main reasons for the failure include inability to meet the requirements of the users, lack of long term development objectives, lack of systematic institutional arrangements and inadequate local man power development.

The failure of reaching the expected outcomes during the second phase of ICPs from 1970s to 1980s made researches to shift the emphasis towards the requirements of stove users. By this time, it was understood that in addition to the above mentioned criteria, factors such as cooking comfort, smoke free kitchen, convenience and safety in the use of stove were considered by the users to be as important as fuel saving. As a result, during the third phase ICPs have been based on much broader objectives. Apart from the benefits of fuel and money savings, other benefits such as smoke reduction, time saving, safety in the kitchen, income generation, improved status of women, increased environmental awareness, etc. have also included as programme objectives (Ramakrishna 1991). A World Bank report cited 137 ICPs in 41 developing countries initiated during 1981-1991. In Asia, although ICPs were initiated in probably all countries, the biggest programmes were undertaken in China where 129 million stoves were installed by early 1992 and in India, where 23.5 million stoves were installed by middle of 1997.

3. Traditional Technologies in Sri Lanka

Most of the Sri Lankan households use either three-stone stove or semi-enclosed mud stove (similar to U-Chulah) for their daily cooking (see Figure 3). Stoves are placed sometimes on the floor level and sometimes on a platform of up to a meter in height.

(*a*) Semi-enclosed Stove

(*b*) Tree-stone Stove

Figure 3: Traditional cook stoves used in Sri Lanka

These traditional stoves are usually built by the users themselves. In general, two (or some time three) units are placed side by side with a shared central wall. A wooden frame is generally constructed above the stove to facilitate drying of fuelwood and other products. The results of a previous survey (Wijesinghe 1983) revealed that majority of households in Hill Country as well as the Rubber growing areas of the wet-zone use semi-enclosed mud stoves. Further, this type is also used by less than half (around 40-45%) of the households in the Dry Zone and Wet Zone coconut areas, where fuelwood is more abundantly available, and less energy efficient three-stone type is more popular (around 50-60%). In the estate sector, almost all households use semi-enclosed mud stoves.

4. Cookstove Development Activities in Sri Lanka

The interest in cookstove development activities in Sri Lanka started in early 1950s. These activities were initiated among the migrated South Indian community worked in the tea plantation concentrated in the central part of the country and therefore influenced by the interests generated in South India. Number of improvements were introduced to the traditional stoves, for example use of muti-pot hearths (see Figure 4). However these improved practices were mainly limited to the South Indian Community, probably because of their poor accommodation facilities which required all household activities to be carried out within a limited space and the strict measures adopted to conserve high land forests. Further, fuelwood was freely available in other parts of the country and there was a lack of interests and awareness on ICS activities.

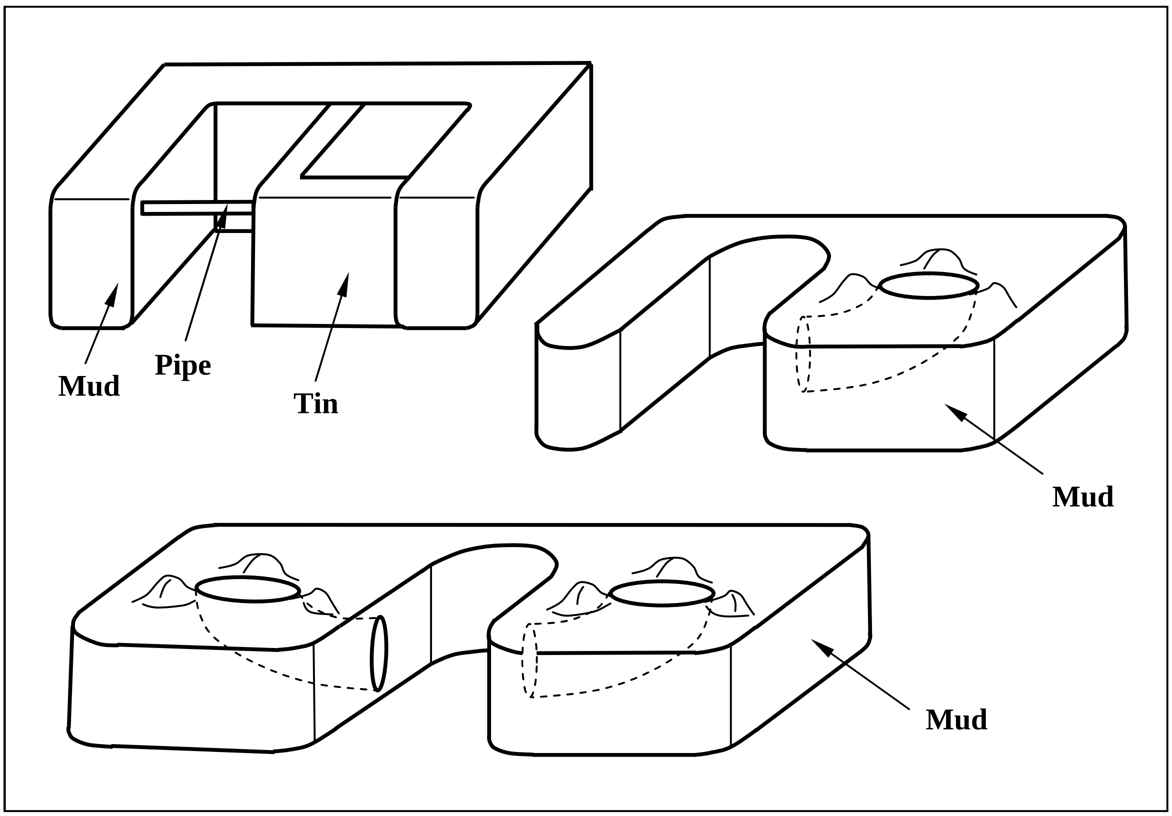


Figure 4: Cook stoves used in the plantation area by the South Indian community.

During 1950s to 1970s a number of government institutes, non-government agencies and private individuals were attempted to introduce new stove designs with the objective of improving kitchen environment and hygienic conditions. One such design was 'Herl Chula' model, which was popular in South India (see Figure 5). However, as in other regions of the world, none of these efforts had any significant impact.

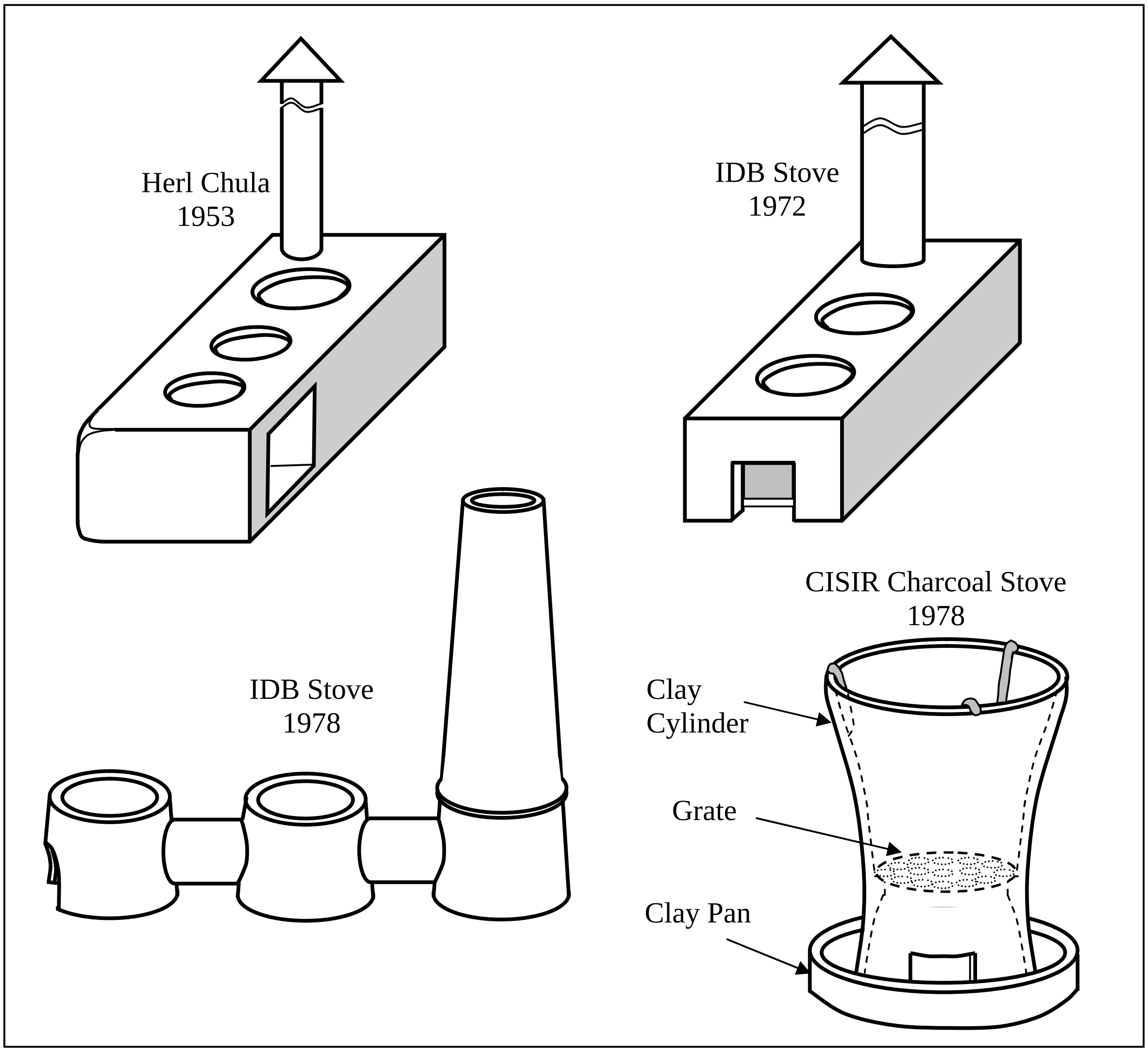


Figure 5: Improved cook stoves disseminated in Sri Lanka during 1950 - 1978

By late 1970s, the deforestation in the country became a severe problem and within two decades forests cover reduced by 50%. In consequence environmental changes and fuelwood scarcity started to take place, and there were significant increases of prices of fuelwood in the urban areas. With the background of these critical situations, "Sarvodaya", a leading non-governmental community development organization, started the Sarvodaya Wood Stove Project in 1979. This programme had broader objectives and had a tremendous impact on the improved cookstove developments in Sri Lanka. The main objectives of the programme could be summarized as follows:

To reduce the time spend for gathering fuelwood and cooking and thereby assist rural women
To reduce the exposure to smoke during cooking, thus improve their health
To reduce the general level of dirt in the kitchen and thereby creating a more pleasant and more hygienic working environment
To protect the environment by reducing the need for people to cut down trees for fuelwood.

As a preliminary study Sarvodaya carried out a detailed survey on different aspects related to cooking including traditional fuels, kitchens, stoves and cooking practices in Sri Lanka. Based on the findings, Sarvodaya started ICS design and development programme for the rural households in the country. A series of models were introduced and it took around three more years to develop a satisfactory design. These activities were supported in different ways by number of other organizations including Intermediate Technology Development Group (ITDG), Novid (Holland), Helvetas (Switzerland), Vita and ATI (USA), Dian Desa (Indonesia) and Gandhiniketan Ashram (India). During the same period, CISIR and IDB too were involved with their own stove development activities and came up with number of improved stove designs (see Figure 5).

The first stove model introduced by Sarvodaya was Lorena stove adopted in Guatemala, which had four pot holes, a chimney, and a special combustion chamber. However, this model did not appeal to Sri Lankan users, as it possessed radical change to the existing practice in Sri Lanka. For instance, it was far larger than the traditional stoves and could only be built by specialist stove builders hence more expensive. Further, only two of the four pot holes were usually in use at a time resulting loss of energy through other two and the total fuelwood consumption actually increased. Based on this experience, Sarvodaya realized that the more feasible way is to modify the existing models than introducing a new design. Sarvodaya looked more closely at existing design and practice and number of models were developed, each design been a modification of the previous one. These modifications include use of only two pot holes, elimination of the chimney, incorporation of smoke vents around the second pot hole, repositioning of the fire hole, etc. By mid 1982, an acceptable design was evolved targeting for users in the rural areas, which is basically a two piece two pot pottery liner stove with a mud insulation.

The ICS model developed by Sarvodaya was first disseminated in Kandy District and thousands of stoves were installed. National Fuelwood Conservation Programme (NFCP) launched by the Ministry of Power and Energy in 1984 promoted these dissemination programmes. Number of other government and non-government organizations offered their support and dissemination of Sarvodaya stoves were extended to Ratnapura and Hambantota districts. A number of training programmes for potters and stove builders were organized. Following years, much larger dissemination programmes, covering the districts of Kurunegala, Kegalle, Gampaha, Kalutara, Matale, Kandy and Nuwara Eliya, were initiated under Sri Lanka-Netherlands Energy Programme (Van der Knyff 1988). Further, SIDA and NORAD (the Swedish and Norwegian government aid agencies) funded the programmes conducted at Matara in 1987 and Monaragala in 1988. These dissemination programmes had led to the installation of more than 100,000 stoves by the beginning of 1988.

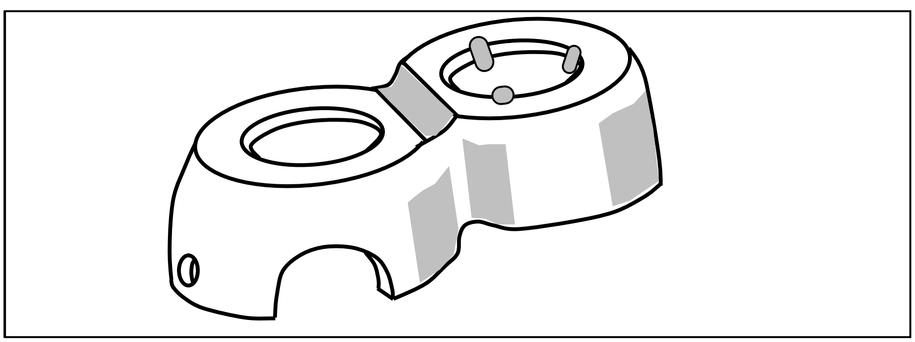


Figure 6: Sarvodaya two pot pottery liner stove with a mud insulation (1983).

The other major impact on the improved cookstove developments in Sri Lanka was due to the collaborative programme initiated in 1987 between Ceylon Electricity Board (CEB), ITDG and a small number of private sector tile manufacturers. This programmed aimed at the urban market and the designs were based upon modified versions of the Sarvodaya stove. Two basic designs were promoted, a single pot stove (Anagi - 1) and a two pot stove (Anagi - 2). Anagi - 2 stove is similar to the Sarvodaya stove except that it is made in one piece and can therefore be used without having to be covered with mud slurry. This model has played a major part in the new promotion but Anagi - 1 has played a relatively minor role (see Figure 7). Although Anagi - 2 was developed mainly for users in urban area, it is also popular in rural areas and a large number of stoves have been disseminated.

(a) Anagi - 1

(b) Anagi - 2

(c) IDB Stove

(d) NERD Center Stove

Figure 7: Improved cook stoves developed during 1983 - 1987.

During the period 1983 - 1987, Ceylon Institute of Science and Industrial Research (CISIR) developed a single pot stove. In 1989, industrial Development Board (IDB) and National Engineering Research & Development Center (NERD Center) independently developed two different single pot stoves (see Figure 7). However these designs were not so popular as Anagi - 2 model.

More recently the Integrated Development Association (IDEA) has been involved with production, marketing and distribution of Anagi - 2 stove model among the rural and urban household sector. According to IDEA, more than 810,000 Anagi - 2 stoves have been disseminated since 1991. Apart from the improved cookstove development programmes conducted first by Sarvadaya and then by CEB described above, none of the other designs and development programmes had any satisfactory impact.

5. Present Status

It has been estimated that, in 1997 approximately 97% of the population in rural areas use fuelwood for cooking and the corresponding percentage in urban areas is 78%, giving 93% in total (FSMP 1995). Note that 79% of the total population in the country live in rural areas. According to a recent survey conducted by the Energy Conservation Fund (ECF) the utilization pattern of the three categories of stoves in rural areas is three-stone - 47%, semi-enclosed - 32% and ICS - 21%. The corresponding percentages in urban areas are 56%, 31% and 13%, respectively.

Table 3: Stoves distribution in urban and rural sector of Sri Lanka

Stove type	% of Number of housing units	
	Rural	Urban
Traditional three stone stoves	47	56
Semi enclosed stoves	32	31
ICSs (Anagi and Sarvodaya stoves)	21	13

From these data, it could be estimated that approximately the percentage shares of fuelwood consumed in the three categories of stoves are 60.4% in three-stone cook-stoves, 27.4% in semi-enclosed stoves and 12.2% in ICS. Note that these results give per capita fuelwood consumption of the three stove categories in 1997 as 1.65 kg/day/person, 1.14 kg/day/person and 0.82 kg/day/person, respectively, with a per capita consumption of 1.33 kg/day (Perera et al. 2000). Similar estimations were reported by Sepalage & Amarasekara (1987), where the corresponding values were 1.50 kg/day/person, 1.11 kg/day/person and 0.99 kg/day/person.

Table 4:. Per capita consumption of stoves in Sri Lanka.

Type of stove	Per capita consumption (kg/day/person)	
	Ref: Sepalage & Amarasekara (1987)	Ref: Perera et al. (2000)
Traditional three stone stove	1.50	1.65
Semi enclosed stove	1.11	1.14
ICS	0.99	0.82

Thus total fuelwood consumed by different cookstoves could be estimated. Since the total fuelwood consumption in the household sector during 1998 is 8327 kt (ECF 1999), fuelwood consumption by the three types of stoves are as given in Table 5.

Table 5: Total annual fuelwood consumption by stoves

Type of stove	Percentage share of fuelwood (%)	Fuelwood consumption (kt/year)
Traditional three stone	60.4	5029.5
Semi enclosed stove	27.4	2281.6
ICS	12.2	1015.9
Total		8327.0

Although, different criteria for cookstove testing and their performance indices are established (for example as given in RWEDP 1993), detailed testing of cookstoves in Sri Lanka are yet to be carried out. However, some indicative values for the efficiencies of cookstoves in the country have been reported by Bhattacharya et al. (1999), which are shown in Table 6.

Table 6: Types and efficiencies of cook stoves

Type of stove	TCS/ICS	Efficiency (%)	Fuel type
Three stone stove	TCS	8.0	Fuelwood, agri-residues
Single and two pot mud stove	TCS	13.0	Fuelwood, agri-residues
Anagi stove 1 & 2	ICS	18.0	Fuelwood
Ceylon charcoal stove	ICS	30.0	Charcoal
Sarvodaya two pot stove	ICS	22.0	Fuelwood
CISIR'S single pot stove	ICS	24.0	Fuelwood
IDB stove	ICS	20.0	Fuelwood
NERD stove	ICS	27.0	Fuelwood

Source: Bhattacharya et al. (1999)

At present, number of organizations are involved with cookstove development and dissemination programmes. The Department of Mechanical Engineering, University of Moratuwa undertakes a research and development programme of cookstoves under the Asian Regional Research Programme on Energy, Environment and Climate - Phase II (ARRPEEC-II) funded by SIDA, Sweden. Further, under another research study funded by the Senate Research Council of the University of Moratuwa, the development of a testing facility for cookstoves is in progress. The department is also involved with theoretical modeling of cookstove designs and their combustion characteristics, and there is an ongoing Master of Engineering (M.Eng) research project on the subject. NERD Center too has been working on the development of cookstoves in the recent past and designed a batch type, single pot, gassification based turbo-stove (i.e. air is supplied and controlled by a fan) targeting for domestic cooking in urban sector. The efficiency of this stove is reported to be of the order 30% and the model received an international award for the design. Integrated Development Association (IDEA) is in the process of formulating a network among stakeholders in the country, with the support of the Asia Regional Cookstove Programme (ARECOP).

6. Potential for Savings

As discussed in the previous section, most of the existing biomass energy technologies in the country are traditional and inefficient. Thus utilization of biomass has been resulted in environment & health problems in addition to the wastage of energy. Therefore there is a considerable potential for biomass conservation and mitigation of GHG and other pollutant emissions through efficiency improvements by deployment of modern biomass energy technologies including ICSs. The following sections of the paper is devoted to analyze the fuelwood saving potential and related impacts through the replacement of TCSs by ICSs.

In order to estimate the fuelwood saving potential in domestic sector, the total fuel consumption of each type of cook stoves and their conversion efficiencies are needed. For this estimation, it is assumed that all types of cookstoves used in the country could be classified into three main categories as three-stone stoves, semi-enclosed stoves and improved cookstoves with average efficiencies of 8%, 13% and 18%, respectively.

Using the calculated values of fuelwood consumption given in Table 5 and efficiencies cited above for different types of stoves, the total saving potential of fuelwood could be calculated and the result is presented in Table 7.

Table 7: Fuelwood saving potential in cookstoves

Type of Stove TCS/ICS	Fuelwood Consumption (kt/year)	Efficiency (%)	Annual Fuelwood Saving Potential	
			kt	**PJ**
Three-stone stove (TCS)	5029.5	8.0	2794.2	41.91
Semi enclosed Stove (TCS)	2281.6	13.0	633.8	9.51
ICS (e.g. Anagi-2)	1015.9	18.0	-	-
Total	8327.0	-	3428.0	51.42

Replacement of TCS by ICS would result in total annual biomass savings of 3.43 Mt. With a heating value of 15 MJ/kg, corresponding annual saving potential of energy become 51.42 PJ. These savings could be used more effectively in industrial heating applications or power generation applications, where the conversion efficiencies are much higher. Use of ICS would also lead to a reduction in emission generated from fuelwood use in domestic sector, which is discussed in the next section.

Environmental and Health Implications

The emissions of pollutants during small scale biomass combustion such as in cookstoves is unavoidable due to many factors including the heterogeneous nature of the combustion process, lack of proper control, design constraints, etc. In addition a major part (80-90%) of the potential heat in the fuel is dissipated to the environment due to low efficiencies, resulting in the rise of the kitchen temperature to uncomfortable levels, specially where kitchen ventilation is lacking. The level of pollution and heat dissipation will vary depending on the types of stoves and fuels used.
The rise of pollutant levels and kitchen temperature to uncomfortable levels is also applicable for many ICS designs with no chimney and/or insulation, despite their higher efficiencies. Therefore, ICS designs should not be considered as the only strategy for improvement of the kitchen environment but various other strategies such as fuel upgrading, improved ventilation and switching to cleaner fuels should be incorporated.

The major pollutants that are normally emitted from biomass burning are CO, CH_4, SO_x, NO_x and particulate materials. Note that carbon dioxide does not fall under the category of pollutants. Further, although CO_2 emission is responsible for over 60% of GHG emission, in the case of fuelwood there is no net emission of CO_2 into the environment since plantation of wood captures the emitted amount. The health effects related to indoor air pollution includes two types of respiratory diseases namely Chronic Obstructive Lung Disease (COLD) in adults and Acute Respiratory Infections (ARI) in infants and young children, adverse pregnancy outcome, cancer, etc (WHO 1992). In addition to the level of emission, the exposure level to pollutants and the duration of exposure are important aspects to be taken into account in predicting health effects. Although a number of studies on these aspects has been carried out in developing countries, a systematic study is yet to be carried out in Sri Lanka. However, general emission levels of different cookstoves in the regional level are available, which could be used to predict the overall reduction potential in emissions through deployment of ICSs in the country. It should be noted that in the rural sector of Sri Lanka, significant number of households has well-ventilated, separate kitchens for cooking where the exposure to pollutants definitely be lower than general levels.

In order to predict the total potential for emission reduction in the domestic cooking sector through efficiency improvements, one has to select emission levels of each pollutant from different cookstoves (both TCS and ICS) from the reported values. Since no reported values are available for Sri Lanka, the average of all the emission levels of a given pollutant for similar stoves reported in the region is taken as the emission factor. A comprehensive data on emission factors for biomass energy use in the domestic sector in the region is given in Bhattacharya et al. (2000). Based on these data, the selected emission factors for the three different categories of cookstoves used in the country are presented in Table 8.

Table 8: Selected emission factors for fuelwood fired cookstoves

Device	Emission Factors (g/kg of air dried fuelwood)					
	CO_2	CO	CH_4	TSP	SO_x	NO_x
Three-stone stove (TCS)[1]	1151.35	46.64	7.60	7.60	0.44	1.29
Semi enclosed stove (TCS)[2]	1104.01	74.84	8.69	8.80	0.44	1.25
ICS (e.g. Anagi-2)[1]	1056.66	103.04	9.77	10.00	0.44	1.20

Note: 1. Source: Bhattacharya et al. (2000)
2. Since the efficiency of semi enclosed stove is the average of the other two types, the emission factors are taken as the average of that from other two types.

The estimated fuelwood consumption of the three cookstove categories given in Table 5 and the selected emission factors of different pollutants given in Table 8 can be used to estimate the total annual emissions generated from fuelwood use in domestic cooking. The results are presented in Table 9.

Table 9: Emissions generated from fuelwood use in domestic cookstoves

Device	Fuelwood Consumption (kt)	Total Annual Emission (kt)					
		CO_2	CO	CH_4	TSP	SO_x	NO_x
Three-stone stove	5029.5	5790.7	234.6	38.2	38.2	2.2	6.5
Semi enclosed stove	2281.6	2518.9	170.8	19.8	20.1	1.0	2.8
ICS	1015.9	1073.5	104.7	9.9	10.2	0.4	1.2
Total	8327.0	9383.1	510.0	68.0	68.5	3.7	10.5

As discussed in the previous section, replacement of TCS by ICS would result in total annual biomass savings of 3.43 Mt, which would also result in considerable reductions in emission of pollutants. The estimated reduction in emissions are presented in Table 10.

Table 10: Reduction in emissions through use of ICS in domestic sector

Device		Fuelwood Saving Potential (kt)	Annual Reduction in Emission (kt)					
			CO_2	CO	CH_4	TSP	SO_x	NO_x
Three-stone stove		2794.2	3428.7	4.2	16.4	15.9	1.2	3.8
Semi enclosed stove		633.8	777.7	1.0	3.7	3.6	0.3	0.9
Total	Amount	3427.9	4206.4	5.2	20.1	19.5	1.5	4.7
	%	41.2	44.8	1.0	29.6	28.4	41.2	44.3

In addition to the reduction in emission of pollutants, use of ICS in domestic sector would lead to a reduction in heat dissipation to the kitchen due to higher efficiencies, resulting in more comfortable cooking environment.

8. Conclusions

Biomass, especially fuelwood, is the main source of energy in the country and major share of it is consumed in cookstoves in domestic sector. Although, a number of ICS dissemination programmes have been conducted, the most of the existing cookstoves are traditional and therefore inefficient and resulting in environment & health problems in addition to the wastage of energy. The estimated consumption of fuelwood in ICSs is only about 12%. Therefore there is a considerable potential for biomass conservation and mitigation of greenhouse gas (GHG) and other pollutants emission through dissemination of ICSs. The present study shows that the saving potential of fuelwood is about 41% and in general, there is a significant reduction in emission of pollutants. Emission factors of various pollutants are not available for Sri Lankan cookstove types and the values used in the present study are based on the reported values in other countries in the region. In addition, other information related to environment and health implications such as the exposure level to pollutants and the duration of exposure are not available. Therefore systematic studies on these aspects are much needed for predicting the impact of dissemination of ICSs, and even for design of ICSs.

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