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# A Study on Population Growth and Environmental Sustainability of a Wood Fuel Based Energy System

## Introduction

THE present paper addresses the problem of sustainability in the context of rapid population growth on the one hand and inefficient mode of utilisation of biomass energy on the other, through a case study—that of Gorubathan block in Darjeeling district of West Bengal. Whether the solely wood-fuel based and grossly inefficient energy consumption pattern can meet the growing energy needs on account of population growth in the block in the coming years has been examined in respect of demand-supply gap (assuming natural growth of forest) as well as environmental considerations (i.e. greenhouse gas emissions and the carbon balance).

The paper comprises three sections. Section I presents the socio-economic features and wood-fuel requirements of Gorubathan block as well as the gaseous emissions arising from wood-fuel burnt in open chulha and improved chulha. In Section II, the natural forest growth required for absorption of carbondioxide, released by biomass burning in chulha, has been estimated. Conclusions drawn from the study have been presented in Section III.

## SECTION I

### Source of Data

Gorubathan block is located in the Kalimpong subdivision of Darjeeling district, West Bengal. A field survey of the block was conducted in the year 1991. The block comprises 36 villages under 4 gram panchayats but there is no town. Due to the large

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number of villages involved, the survey was carried out on the basis of selected samples—18 villages were selected for survey from the four gram panchayats in consultation with the Block Development Office at Gorubathan. The selection of villages was largely based on topographical and administrative consideration. Complete enumeration of households in the selected villages was carried out.

**Socio-economic Features of Gorubathan Block**

The total land area of the block is about 447 sq. km. Forests cover 63 percent of the land area. There are six tea gardens in the block. The total population of the block in 1991 was 46382. In 1981, the population was 40178 showing a decadal growth rate of 15.44 percent, as per Census 1991. The block exhibits the typical features of a hilly region low density of population, houses built of wood, acute scarcity of good quality drinking water during a large part of the year, poor communication facilities, inadequate medical and educational facilities, and a low literacy rate (37 percent). Only 38 percent of the population constitutes the workforce. Although agriculture is the predominant occupation, there is single crop cultivation which in turn implies widespread seasonal unemployment. There is considerable disparity in income distribution in the block. A large proportion of households (44.07 percent) falls within the low income group with annual household incomes upto Rs. 6000/-. while 29.17 percent and 26.76 percent of the households come under the middle income (ranging between Rs. 6001/- to Rs. 12.000/-) group, and high income (above Rs. 12.000/-) group respectively (Banerjee. 1998).

**Woodfuel Requirements of Gorubathan Block**

As in many hilly areas, fuelwood is the primary fuel used in Gorubathan block. Available data indicate that 90 percent of the energy needs for cooking—the major end-use activity—is met by fuelwood. The local population have long been habituated to the use of fuelwood burnt in U-shaped open chulhas which produces much smoke thereby polluting the atmosphere and causing health hazards (Banerjee *et al*.. 1992). Besides, the combustion efficiency of the traditional open chulha being very low. the quantity of fuelwood required to produce the effective heat energy for cooking is large which has been one of the factors responsible for accelerating the pace of deforestation. Per capita energy consumption of Gorubathan block stood at $1961 \times 10^3$ kilocalories in 1991 corresponding to which the useful energy (i.e.. energy obtained at the users' end) works out to only $144 \times 10^3$ kilocalories. This inefficient energy utilisation pattern based solely on fuehvood gives rise to the question of sustainability—whether such an energy consumption^ pattern can sustain the growing energy needs of the Block in the coming years.

*Methods of Estimating Future Demand*

Estimates of future woodfuel requirements of the Block (extending upto the year 2011) have been presented in Table 1. Population figures have been arrived at on the basis of projected growth of population (based on projections made by the Planning Commission). at the following growth rates: 1.74 percent per annum for 1991-96, 1.53 percent per annum for 1996-2001, 1.35 percent per annum for 2001-2006, 1.19 percent per annum for 2006-2011. Woodfuel requirement of the years 2001. 2006 and 2011 have been estimated on the assumption of growth in energy demand at the rate of 2 percent per annum.

TABLE 1: ESTIMATES OF FUTURE WOODFUEL REQUIREMENTS IN GORUBATHAN

| *Year* | *Population* | *Number of Households* | *Total Fuelwood requirement,* kg |
|---|---|---|---|
| 1991 | 46382 | 9276 | $18.42 \times 10^6$ |
| 2001 | 53670 | 10734 | $22.45 \times 10^6$ |
| 2006 | 57934 | 11587 | $24.80 \times 10^6$ |
| 2011 | 61380 | 12276 | $27.37 \times 10^6$ |

## Energy Conversion Device for Cooking

The U-shaped open chulha made up of mud has traditionally been in use in Gorubathan block. Fuelwood mainly, and to a small extent, agricultural residues burnt in U-shaped open chulha provides the energy requirements for cooking purposes. This chulha has a very low thermal efficiency ranging between 5 to 10 percent.

An alternative energy conversion device to the traditional open chulha, which ranks high from the point of view of acceptability by the rural population is the improved chulha. It does not involve very high cost of construction/installation or any complex mode of operation and maintenance.

Broadly, improved chulhas are of two types, namely, fixed chulhas made up of mud. clay. bricks and chimney; and portable chulhas made of metal. The maximum thermal efficiency is over 20% and 25% for fixed and portable chulhas respectively (MNES, 1992-93).

As the improved chulha has about two and half times higher thermal efficiency than the traditional chulha, it requires a much smaller quantity of fuelwood to produce the same amount of effective heal energy at the users' end as the open chulha. This is shown in Table 2.

The improved chulha is fitted with a chimney for outlet of smoke and, therefore, it does not involve health hazards or damage to houses on account of indoor air pollution. Nevertheless, fuelwood burning in whatever device it may be, always involves environmental degradation arising out of emissions of green-house gases. However, the improved

TABLE 2: ENERGY OBTAINED FROM FUELWOOD IN GORUBATHAN BLOCK

| | *Open Chulha* | *Improved Chulha* |
|---|---|---|
| Total Quantity of Fuelwood Used Annually (kg ) | 18.42 x lo$^6$ | 7.36 x $10^6$ |
| Total Annual Effective Energy Obtained at Users' End ($10^3$ Kcal) | 6.57 x $10^6$ | 6.57 x $10^6$ |

chulha is superior to the open chulha even in this respect as it requires smaller quantity of fuelwood than the latter.

The emission factors for fuelwood burnt in open chulha and in improved chulha are presented in Table 3.

TABLE 3: EMISSION FACTORS, Kg Per Kg OF DRY FUEL

| | | | | *Products of Incomplete Combustion (PICs)* | | | |
|---|---|---|---|---|---|---|---|
| *Fuel* | *Carbon* | *Stove* | CO, | CO | CIL. | TNMOC | SP |
| Wood | *0.5* | 0.08 | 1.613 | 0.101 | 0.011 | 0.0013 | 2 x $10^3$ |
| (1 kg dry) | 0.5 | (Open Chulha) | 1.62 | 0.099 | 0.009 | 0.012 | 2 x 10-$^3$ |
| Wood | | 0.20 | | | | | |
| (1 kg dry) | | (Improved Chulha) | | | | | |

*Source:* Kirk R. Smith (1994).
*Note:*

$CO_2$ Carbon dioxide
CO Carbon monoxide
$CH_4$ Methane
TNMOC = Total Non-ethane organic compounds.
SP Suspended particulates. considered 75% carbon

The table shows that carbon-dioxide emission is marginally less in open chulha as compared to that in unproved chulha. But emissions of products of incomplete combustion (PICs)—carbon monoxide, methane and non-methane organic compounds in particular, are higher for the open chulha as compared to the improved chulha.

## Fuel Requirement and Emission Factors Per Household

The annual fuelwood requirement and emission factors due to fuelwood burning per household in Gorubathan block have been presented in Table 4.

Scenario 1 represents the existing situation where fuelwood is burnt in open chulha for meeting the energy requirements for cooking only. In Scenario II, improved chulha is introduced for cooking.

In Scenario I, where fuelwood is burnt in traditional open chulha for cooking, the annual fuelwood requirement per household is 1986 kg. This quantity ofwoodfuel burnt in open chulha produces annually 3203 kg of carbon-dioxide, 200 kg of carbon-monoxide and 51.6 kg of other products of incomplete combustion (Table 4).

Improved chulha introduced for cooking requires a smaller quantity of fuelwood— 794 kg per household per year—than the open chulha to meet the same level of energy needs (as in open chulha), of a household for low and medium temperature heating. The emission factors corresponding to 794 kg of woodfuel burnt in improved chulha are 1286 kg of carbon-dioxide, 78.6 kg of carbon monoxide and 18.3 kg of other PICs. Thus Scenario II while meeting the annual energy requirements of a household for cooking purposes, involves release of lesser quantities of pollutants as compared to Scenario I. The amount of carbon-dioxide released is 60 percent less, that of carbon-monoxide and other PICs 61 and 65 percent less respectively, than in Scenario I.

TABLE 4: ANNUAL FUELWOOD REQUIREMENT AND EMISSION FACTORS DUE TO FUELWOOD BURNING FOR A HOUSEHOLD IN GORUBATHAN BLOCK. Kg/Year

| *Different Scenarios* | *Fuel/ Activities* | *Annual Fuelwood consumption* (kg) | *Emission Factors* | | |
|---|---|---|---|---|---|
| | | | *Carbon-dioxide* (kg) | *Carbon-monoxide* (kg) | *Other PICs* (kg) |
| Scenario I | Fuelwood/ cooking open chulha | 1986 | 3203 | 200 | 51.6 |
| Scenario II | Fuelwood/ cooking in improved chulha | 794 | 1286 | 78.6 | 18.3 |

**Estimates of Future Emission Factors from Fuelwood Burning in Gorubathan Block**

On the basis of estimates of future woodfuel requirements (Table 1), annual emission factors due to fuelwood burning in Gorubathan block have been estimated for the years extending upto 2011 in Table 5. Emission of carbon-dioxide in Scenario II will be 17.85 x $10^6$ kg in 2011. This is 60 percent less as compared to carbon-dioxide emissions in Scenario I. Release of carbon-monoxide due to burning of fuelwood in improved chulha is estimated to be 0.91 x $10^6$ kg in 2001, 0.99 x $10^6$ kg in 2006 and 1.09 x $10^6$ kg in 2011. Emissions of other PICs in Scenario II are estimated at 0.21 x $lo^6$ kg in 2001, 0.23 x $l0^6$ kg in 2006 and 0.25 x $l0^6$ kg in 2011.

TABLE 5: ESTIMATES OF FUTURE FUELWOOD REQUIREMENTS AND EMISSION FACTORS DUE TO FUELWOOD BURNING IN GORUBATHAN BLOCK. Kg/Yr

| *Different Scenarios* | *Year* | *Combustion Device* | *Fuelwood Requirement* kg/yr | *Emission for wood burning* kg/yr | | |
|---|---|---|---|---|---|---|
| | | | | $CO_2$ | CO | *Other PICs* |
| Scenario I | 1991 | Open Chulha | $18.42 \times 10^6$ | $29.70 \times 10^6$ | $1.86 \times 10^6$ | $0.48 \times 10^6$ |
| | 2001 | Open Chulha | $22.45 \times 10^6$ | $36.21 \times 10^6$ | $2.27 \times 10^6$ | $0.58 \times 10^6$ |
| | 2006 | Open Chulha | $24.8 \times 10^6$ | $40.0 \times 10^6$ | $2.50 \times 10^6$ | $0.64 \times 10^6$ |
| | 2011 | Open Chulha | $27.37 \times 10^6$ | $44.14 \times 10^6$ | $2.76 \times 10^6$ | $0.71 \times 10^6$ |
| Scenario II | 1991 | Improved Chulha | $7.36 \times 10^6$ | $11.9 \times 10^6$ | $0.73 \times 10^6$ | $0.17 \times 10^6$ |
| | 2001 | Improved Chulha | $9.15 \times 10^6$ | $14.82 \times 10^6$ | $0.91 \times 10^6$ | $0.21 \times 10^6$ |
| | 2006 | Improved Chulha | $10.02 \times 10^6$ | $16.23 \times 10^6$ | $0.99 \times 10^6$ | $0.23 \times 10^6$ |
| | 2011 | Improved Chulha | $11.02 \times 10^6$ | $17.85 \times 10^6$ | $1.09 \times 10^6$ | $0.25 \times 10^6$ |

## SECTION II

### Plant as Carbon Dioxide Sink

Burning of fossil fuels and biomass is a major source of emission of carbon dioxide. The only sink for natural absorption of carbon dioxide is plant. Photosynthesis—the process through which plants grow—fix carbon dioxide from the atmosphere into a biomass reservoir in the presence of solar radiation which is absorbed by the vital plant pigment known as chlorophyll. Thus, biomass burning which causes a prompt release of carbon dioxide does not necessarily imply a net release of carbon dioxide to the atmosphere, as the carbon that is lost to the atmosphere may be returned by subsequent regrowth of vegetation. It has been estimated that around $8 \times 10^{14}$ kg of carbon is stored in the global biomass, about 90% of this in trees and only about 2% in the oceans. representing an energy reservoir of some $2 \times 10^{16}$ MJ.

Nevertheless, through biomass burning, there is a net transfer of particulaar matter and trace gases other than carbon dioxide from the biosphere to the atmosphere, many of which play a large role in atmospheric and climatic changes. Recently, rising concerns about global warming from the build up of carbon dioxide, methane and other greenhouse gases in the atmosphere have focussed attention on worldwide biomass combustion.

### Carbon Fixation through Photosynthesis

The basic equation of photosynthesis—the process by which green plants manufacture food—is of the form:

$$CO_2 + H_2O \xrightarrow[\text{Chlorophyll}]{\text{sunlight}} C(H_2O) + O_2$$

Carbohydrate

(12 + 32 = 44 gm) 18 gm — (12 + 2 + 16 = 30 gm) 32 gm

From the above equation, it is observed that for 12 gm of carbon fixed in plant materials. 44 gm of carbon dioxide is absorbed from the atmosphere.

The carbon content of 1 kg of wood is 500 gm (Smith. 1994). Therefore, for the growth of 1 kg of wood (dry) the amount of carbon dioxide absorbed is 1833.33 gm. Therefore, 1 kg of carbon dioxide is absorbed from the atmosphere for the growth of 0.546 kg of plant materials.

This estimate of carbon dioxide absorption from the atmosphere for the growth of plant has been used for estimating the annual forest growth required in Gorubathan block, at present and in future, for sustainability of the woodfuel based energy consumption of Scenario I. and Scenario II. In this paper the block has been considered as closed system, that is. the pollutants released from biomass burning in the block are assumed to remain within the atmosphere of that block only. This assumption is made in order to make estimation possible.

## Forest Growth Required for Absorption of Carbon Dioxide

### *Scenario I*

The natural forest growth required in Gorubathan block for absorption of carbon dioxide emitted due to fuelwood burnt in open chulha at present and in future is shown in Table 6. The region has sub-tropical broad-leaved hill forests, natural growth rate of which is about 6 tonnes per hectare per year (Sagreiya, 1994). (Bisio and Boots, 1995). The growth of leaves and branches is considered to be 10-15 percent of the overall growth. In Table 6. which also shows effective forest yield for use as fuel and the gap between this natural supply and the demand for biomass in Gorubathan block, an average of 12.5 percent of plant growth is assumed as the growth of leaves and branches actually used as fuel (White and Plaskett. 1981). The situation at present where 18.42 x $10^6$ kg of woodfuel is required annually in the block for meeting the present level of energy needed for cooking in open chulha, involves annual emission of 29.7 x $10^6$ kg of carbon dioxide. Absorption of this amount of carbon dioxide would require 16.22 x $10^6$ kg of annual forest growth.

The forest coverage of Gorubathan block being extensive (63% of total land area) and the natural growth rate being high, it is found that the natural growth rate—168.88 $^x$ $10^6$ kg per year—is much higher than that required for absorption of carbon dioxide released annually from burning of biomass in this region. This holds not only at present but also when estimated increases in biomass combustion and resulting increase in carbon dioxide emission in future is taken into consideration as is evident from a comparison of columns 2, 3, 4 and 5 of Table 6. However, the situation is not the same when effective forest yield for burning as fuel is considered.

TABLE 6: FUELWOOD BURNING IN OPEN CHULHA AND NATURAL FOREST GROWTH IN GORUBATHAN BLOCK (By Carbon Balance Technique)

| *SCENARIO I : FUELWOOD BURNING IN OPEN CHULHA* | | | | | | |
|---|---|---|---|---|---|---|
| *Year* | *Annual fuelwood (Biomass) Burning for cooking* (kg) | *Annual CO, emission due to biomass burning* (kg) | *Annual forest growth reqd. for absorption of $CO_2$ only* (kg) | *Annual forest yield due to natural growth* (kg) | *Effective forest yield for burning in chulha (Total yield* x *0.125)* (kg) | *Gap between natural supply and biomass demand (6 -2)* (kg) |
| *1* | 2 | *3* | *4* | *5* | *6* | 7 |
| 1991 | $18.42 \times 10^6$ | $29.7 \times 10^6$ | $(29.7 \times 10^6) \times 0.546 = 16.22 \times 10^6$ | $168.88 \times 10^6$ | $21.11 \times 10^6$ | No gap |
| 2001 | $22.45 \times 10^6$ | $36.21 \times 10^6$ | $20.14 \times 10^6$ | $168.88 \times 10^6$ | $21.11 \times 10^6$ | $1.34 \times 10^6$ |
| 2006 | $24.8 \times 10^6$ | $40 \times 10^6$ | $22.07 \times 10^6$ | $168.88 \times 10^6$ | $21.11 \times 10^6$ | $3.60 \times l0^6$ |
| 2011 | $27.37 x'10^6$ | $44.4 \times 10^6$ | $24.25 \times 10^6$ | $168.88 \times 10^6$ | $21.11 \times 10^6$ | $6.26 \times 10^6$ |

The effective forest yield, for use as fuel, out of $168.88 \times 10^6$ kg of annual yield due to natural growth is $21.11 \times 10^6$kg(12.5%). This is greater than the present fuelwood requirement and hence there is no gap between natural supply and biomass demand in the block at present. However, rising energy demand necessitating increasing fuelwood requirements estimated at $22.45 \times 10^6$ kg in 2001, $24.8 \times 10^6$ kg in 2006 and $27.37 \times 10^6$ kg in 2011, cannot be met in full by the effective forest yield at the natural growth rate of forest. The growing gap between natural supply and the demand for biomass has been estimated to be $1.34 \times 10^6$kg in 2001, 3.69 x $io^6$ kg in 2006, and 6.26 x $l0^6$ kg in 2011. This indicates the danger of rapid deforestation in Gorubathan block in the coming years unless appropriate measures are adopted.

*Scenario II*

Burning of lesser quantity of biomass results in reduced carbon dioxide emissions in Scenario II (when improved chulha is introduced in all households of Gorubathan block) as compared to Scenario I. Annual carbon dioxide emission due to burning of fuelwood in improved chulha is estimated to be 11.92 x $l0^6$ kg in 1991, $14.82 \times 10^6$ kg in 2001, $16.23 \times 10^6$ kg in 2006 and $17.85 \times 10^6$kg in 2011. Absorption of these carbon dioxide emission will require $6.51 \times 10^6$kg of annual forest growth in 1991, $8.09 \times 10^6$ kg in 2001, 8.86 x $l0^6$ kg in 2006 and 9.75 x $l0^6$ kg in 2011 (Table 7).

TABLE 7: FUELWOOD BURNING IN IMPROVED CHULHA AND NATURAL FOREST GROWTH IN GORUBATHAN BLOCK (By Carbon Balance Technique)

*SCENARIO II : FUELWOOD BURNING IN IMPROVED CHULHA*

| *Year* | *Annual fuehvood (Biomass) Burning for cooking* (kg) | *Annual CO, emission due to biomass burning* (kg) | *Annual forest growth reqd for absorption of CO-, only* (kg) | *Annual forest yield due to natural growth* (kg) | *Effective forest yield for burning in chiiiha (Total yield* x *0.125)* (kg) | *Gap between natural supply and biomass demand (6 - 2)* (kg) |
|---|---|---|---|---|---|---|
| *1* | 2 | *3* | *4* | *5* | *6* | 7 |
| 1991 | $7.36 \times 10^6$ | $11.92 \times 10^6$ | $6.51 \times 10^6$ | $168.88 \times 10^6$ | $21.11 \times 10^6$ | Nil |
| 2001 | 9.15 x 10" | $14.82 \times 10^6$ | $8.09 \times 10^6$ | $168.88 \times 10^6$ | $21.11 \times 10^6$ | Nil |
| 2006 | $10.02 \times 10^6$ | $16.23 \times 10^6$ | $8.86 \times 10^6$ | $168.88 \times 10^6$ | $21.11 \times 10^6$ | Nil |
| 2011 | $11.02 \times 10^6$ | $17.85 \times 10^6$ | $9.75 \times 10^6$ | $168.88 \times 10^6$ | $21.11 \times 10^6$ | Nil |

As already observed in Scenario I, the natural forest growth per year in Gorubathan block stands at $168.88 \times 10^6$ kg, thus exceeding the requirement for carbon dioxide absorption. In Scenario II, it is further observed that the annual effective forest yield of $21.11 \times 10^6$ kg is also greater than the estimated annual biomass demand in coming years as evident from a comparison of columns 2 and 6 of Table 7. Hence there is no gap between natural supply and biomass demand in Scenario II.

## SECTION III

### Conclusion

The annual estimated yield from natural forest growth in Gorubathan block is more than sufficient for absorption of carbon dioxide released by burning of woodfuel not only at present but also in the coming years for both the scenarios. However, the annual effective forest yield from natural growth which is actually used as fuel falls short of growing woodfuel requirements of the block in the coming years if the existing inefficient energy utilisation pattern is continued.

The gap that emerges between natural supply and biomass demand in Scenario I shows that the present woodfuel based energy system is unsustainable in future. Scenario II, in which improved energy conversion device for cooking is introduced, offers an environmentally sustainable solution to the energy problem of Gorubathan block. Besides, the conservation of woodfuel in Scenario II actually opens up the possibility of its multiple use— for household lighting as well through small scale electricity generation in biomass gasifier.

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