Economic and environmental impact of micro-hydro- and biomass-based electricity generation in the Sri Lanka tea plantation sector

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The production process of tea is such that the industry's maximum power need coincides with the power system peak demand, thus consuming expensive energy. This industry is largely located in the Central, Sabaragamuwa and Uva provinces, where the topography coupled with heavy persistent rainfall offers a good opportunity to harness hydro-power, the most widely used power source in the plantation sector, to meet the entire power requirement of the industry. This potential remains largely underutilised, as grid electricity supply is at present available in almost all tea estates, particularly at the factories where tea is processed. These plantations also practise cultivation and harvesting of fast-growing tree species in abandoned tea-growing land to meet the industry's thermal energy requirements. This biomass usage could also be extended to electricity generation, though realising the scope for this application in the Sri Lankan context is in an experimental stage.

Widespread use of these two indigenous energy sources by the plantation industry can be expected to reduce the peak demand while making the cost of electricity in the sector less sensitive to external factors. Further, the use of micro-hydro and biomass can contribute to the reduction of undesirable environmental impacts associated with electricity generation.

The paper discusses a detailed estimation of the aggregate potential of biomass- and micro-hydro-based energy supplies in the tea plantation sector. Also, its substitution effect on demand for electricity in the sector in terms of its economic impact both in the plantation sector and in the national energy scenario is examined.

1. Introduction

The history of the Sri Lankan tea industry dates back to 1867, after the destruction of the coffee industry by the coffee rust disease. For many years it has been one of the mainstays of the Sri Lankan economy. The tea industry contributed about 2.2 % of value added in the national GDP in 1996 and the figure is likely to be similar in the future. This sector consists of several elevation-related varieties of tea, low-grown, medium-grown and high-grown tea, covering an extent of approximately 187,000 ha. The crop prduced was a record 258 million kg in 1996, and high-, medium-, and low-grown tea accounted for 28 %, 19 %, and 53 % in the total respectively (see Figure 1). Production trends indicate that low-grown tea production has been increasing continuously over the years with an increase of well over 90 million kg during the last four decades [Sri Lanka Tea Board, 1997].

Tea production has recently shown an increasing trend, particularly after privatisation of management of estate lands in 1992. It is, however, expected to stabilise at about 300 million kg per annum in the future. A main constraint in increasing the production rate is the limited land resources available for tea cultivation, given other needs such as agriculture and urbanisation and, to a lesser extent, factors such as failure to develop new high-yielding tea species.

Another important aspect of the Sri Lankan tea sector is its relatively high cost of production in comparison to other tea-producing countries, low labour productivity and limited labour mobility.

In relation to labour resources, the tea sector employs approximately 320,000 registered workers, and only 10 of the 25 plantation companies reported surplus labour[1]. Labour costs alone constitute about 65 % of the total cost of production, primarily because of the adoption of labour-intensive technology and increased wage rates. Alternatives such as mechanical tea-plucking are inappropriate in Sri Lanka because of social problems one may encounter with heavy redundancies accompanying mechanisation. The labour-intensive nature of production implies continued rises in the labour component of the total cost of production in the future [Dunham et al., 1997].

The cost of producing a kg of processed tea was Rs. 90.75 in 1996, showing an increase by 18 % when compared to 1995 [Central Bank, 1997]. This was mainly because of increased wage rates and an incentive payment

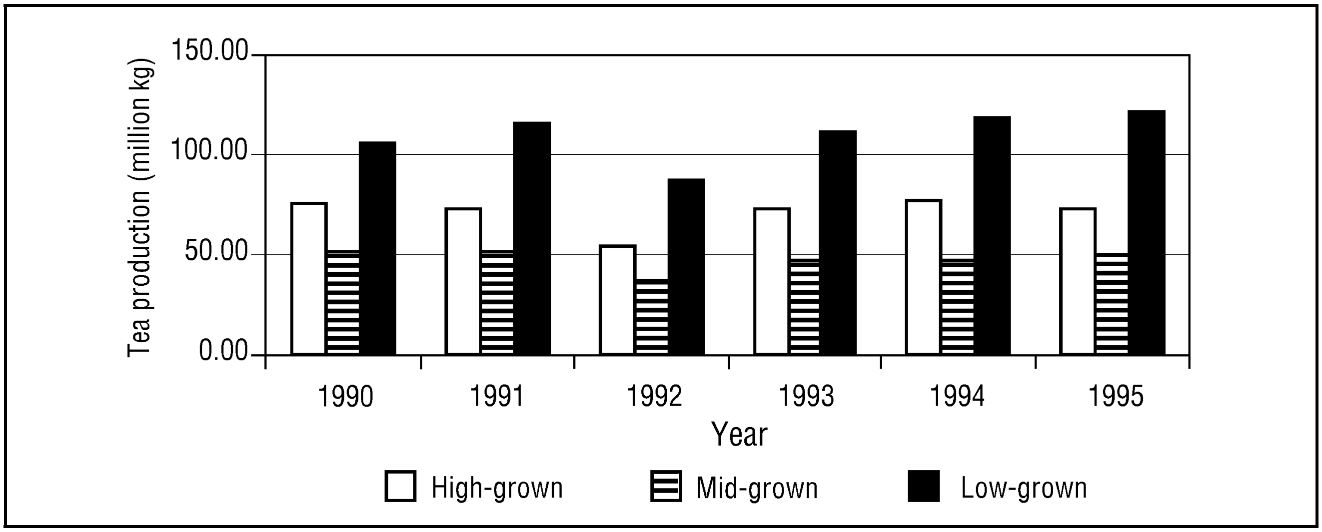

Figure 1. Tea production figures by area (in million kg)
Source: Sri Lanka Tea Board, 1997

based on the net average sales during the year [Central Bank, 1997]. Therefore, the cost of labour is likely to continue to be a critical factor in exerting further pressure on the already high cost of production. Sri Lanka's cost of production in the tea sector is seen to be relatively high, about 35 % higher than Kenya's and 40 % higher than Indonesia's.

2. Tea sector's energy needs

The tea processing industry is responsible for a substantial part of the energy consumption of the industrial sector in the form of electricity, fuelwood, and oil. Energy consumption by this sector is one of the largest as a sector. Overall, electricity consumption was 5.4 % of total sales and 14.25 % (amounting to 194 GWh) of total industrial consumption in 1996. The energy component in the cost of production of processed tea ranges between 5 and 14 % in general, considering electricity and fuelwood. But these figures are likely to change with recent increases in grid tariffs with the introduction of high-cost generation supply options. There are regional differences in electricity consumption within the tea sector as given below.

- *Upcountry:* 0.9-0.95 kWh/kg of processed tea
- *Mid-country:* 0.62-0.82 kWh/kg of processed tea
- *Low-country:* 0.65 kWh/kg of processed tea

Benefits at the estate level can be realised both by reduction of energy consumption associated with grid electricity and by shifting from grid electricity to other forms of renewable energy options such as micro-hydro and biomass. These options also serve as reliable stand-by power supplies in instances of grid failures which would result in losses due to tea being spoilt during such failures in the middle of the production process.

Sri Lankan tea factories at present heavily depend on fuelwood transported from areas outside the tea-producing regions, with most estates producing only a small proportion of their own needs. A major part of this fuelwood requirement (69 %) comes from rubber plantations. The need for fuelwood plantations has already been highlighted as a means of negating the harmful effects of deforestation in the country's traditional forests and becoming more self-sufficient at a regional level in such resources [Sri Lanka Tea Board, 1997].

3. Electricity demand profile of the tea sector

Monthly demand profiles of the tea sector in the three regions are required for use as an input to the generation planning software for analysing the impact of micro-hydro and biomass power on the national electricity generation expansion plan. The monthly demand profile is assumed to be a repetitive daily demand profile in the tea sector for 26 days (or 24 days in February) since the tea factories tend to operate every day except on Sundays. Daily load curves of representative tea factories were obtained from the national data sources including at least three estates/factories in each of the three regions considered. National secondary source data from detailed energy audits at a few tea factories in these regions is also used. The daily demand profile for the entire tea sector is computed combining all the data from three geographical regions. This is shown in Figure 2.

3.1. Regional tea sector daily demand profile

The above aggregate demand for the tea sector can be disaggregated into the demand profiles of high-, medium- and low-grown tea region demand patterns. These are shown in Figures 3a, 3b and 3c.

Using the monthly demand profiles obtained as discussed, the monthly load duration curve (LDC), the load level versus the duration that demand exceeds this level, is derived for each region for one-hour intervals. The LDC is the form of the input required for the planning tool.

4. Estimation of micro-hydro and biomass potential energy supply for the tea plantation sector

Figure 4 illustrates monthly technical potential estimates of micro-hydro and biomass energy supply in the tea sector as compared with national grid energy.

4.1. Micro-hydro supply estimates

The study on micro-hydro potential is based on the survey conducted by the Intermediate Technology Development

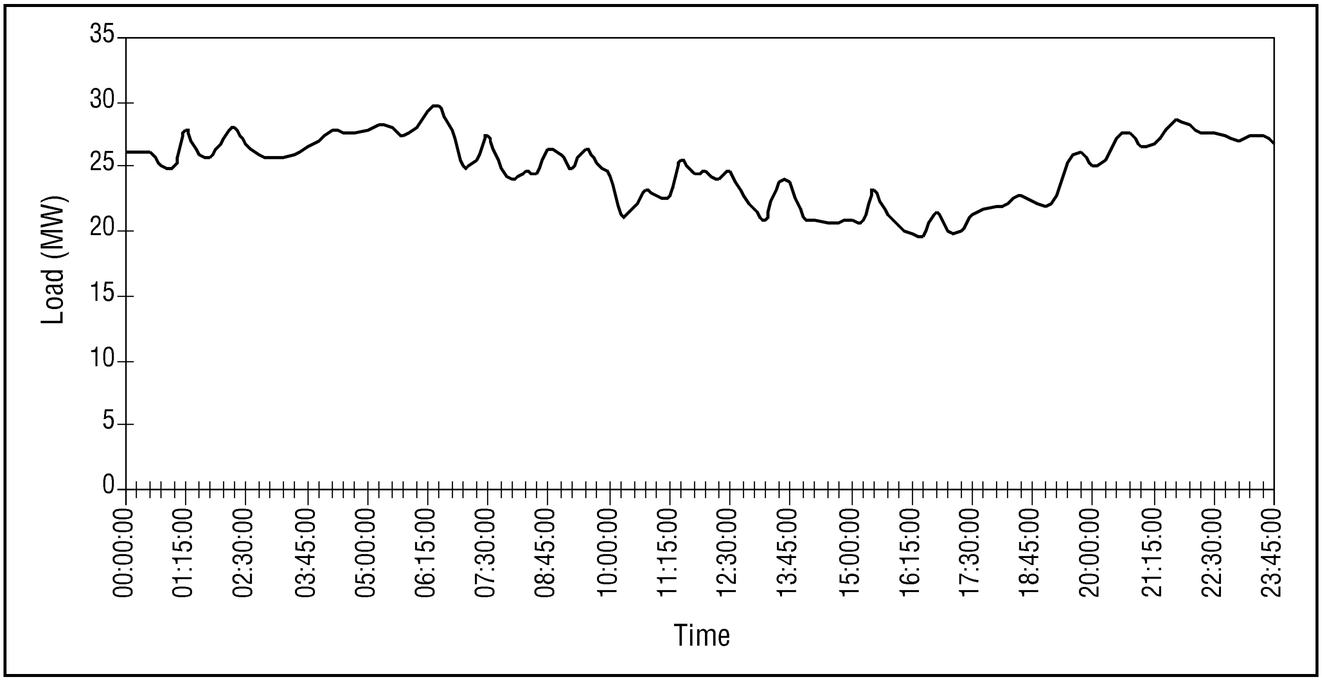

Figure 2. Aggregate electricity demand profile in Sri Lanka's tea sector
Source: Dhanapala et al. [1998]

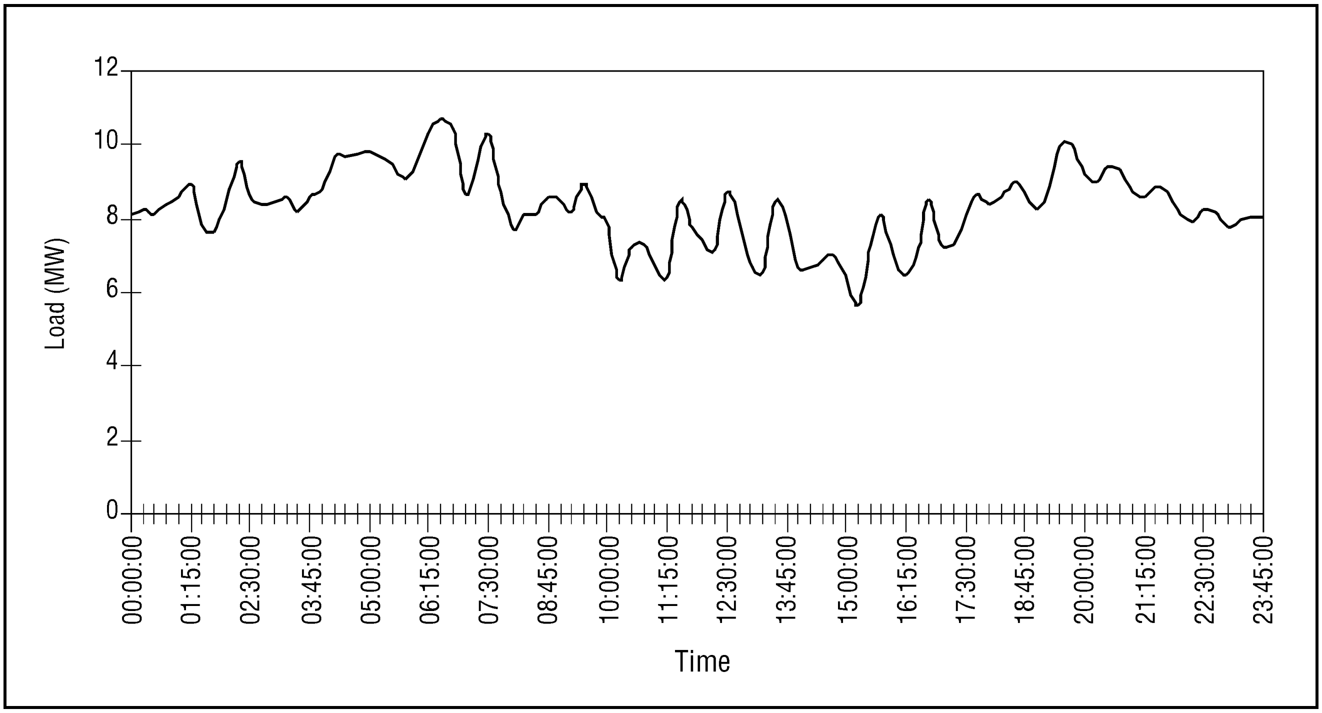

Figure 3a. Daily load demand curve for high-grown tea region
Source: Dhanapala et al. [1998]

Group (ITDG) on micro-hydro in the estate sector in 1996-97. This survey was conducted by technical personnel equipped with the necessary equipment to measure and evaluate the hydro-power potential at a site. Altogether, 206 sites have been investigated in the up-, mid- and low-country regions. Most of the hydro sites are located within tea estates [ITDG, 1997].

Hydro sites with power potential in the range of 8 kW to 3067 kW are included in the database. The survey results shows that about 35 % of the sites in the database are abandoned, 20 % are in operation and 36 % are new sites in the vicinity of estates. It is observed that at most of the sites the potential can be increased either by increasing the head or the flow or both [Dhanapala, 1996].

In order to analyse the impact of micro-hydro supply on the national power system it was necessary to estimate the monthly energy availability of each plant.

4.2. Biomass supply estimates

Unlike micro-hydro or wind power, biomass energy is by and large independent of seasonal variations. This would

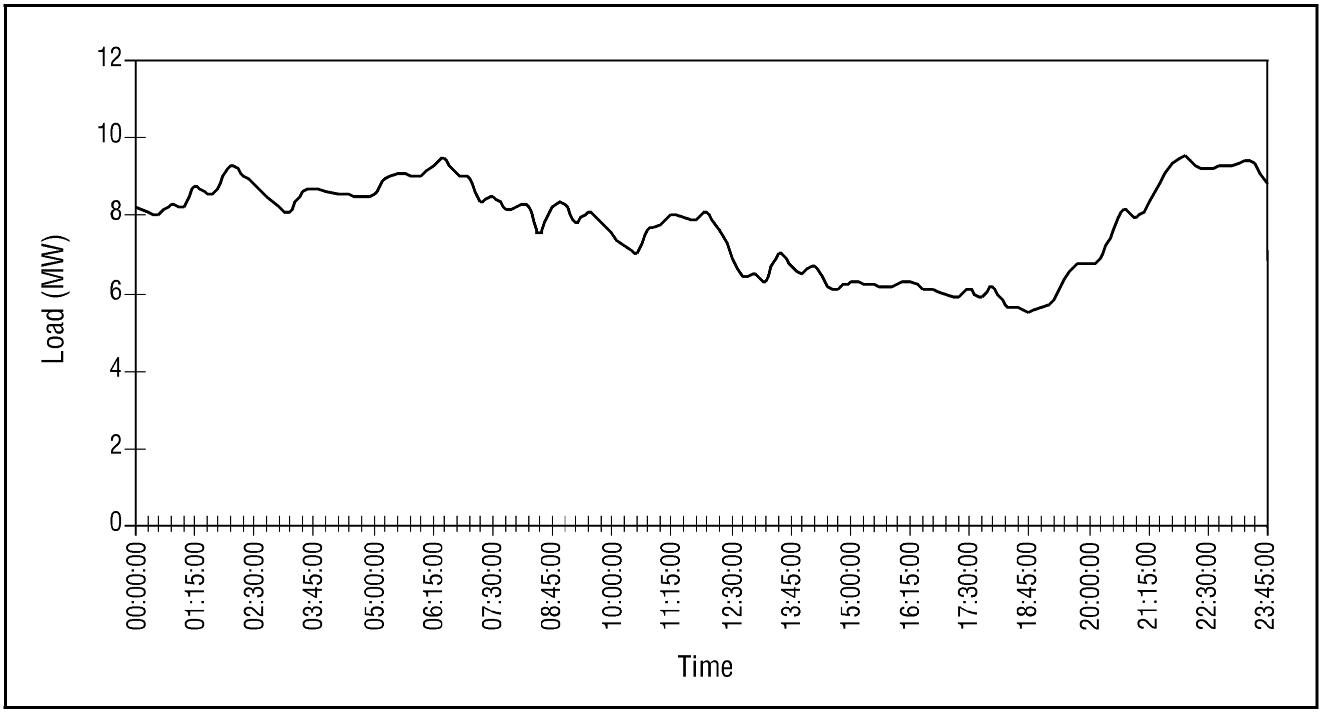

Figure 3b. Daily load demand curve for mid-grown tea region
Source: Dhanapala et al. [1998]

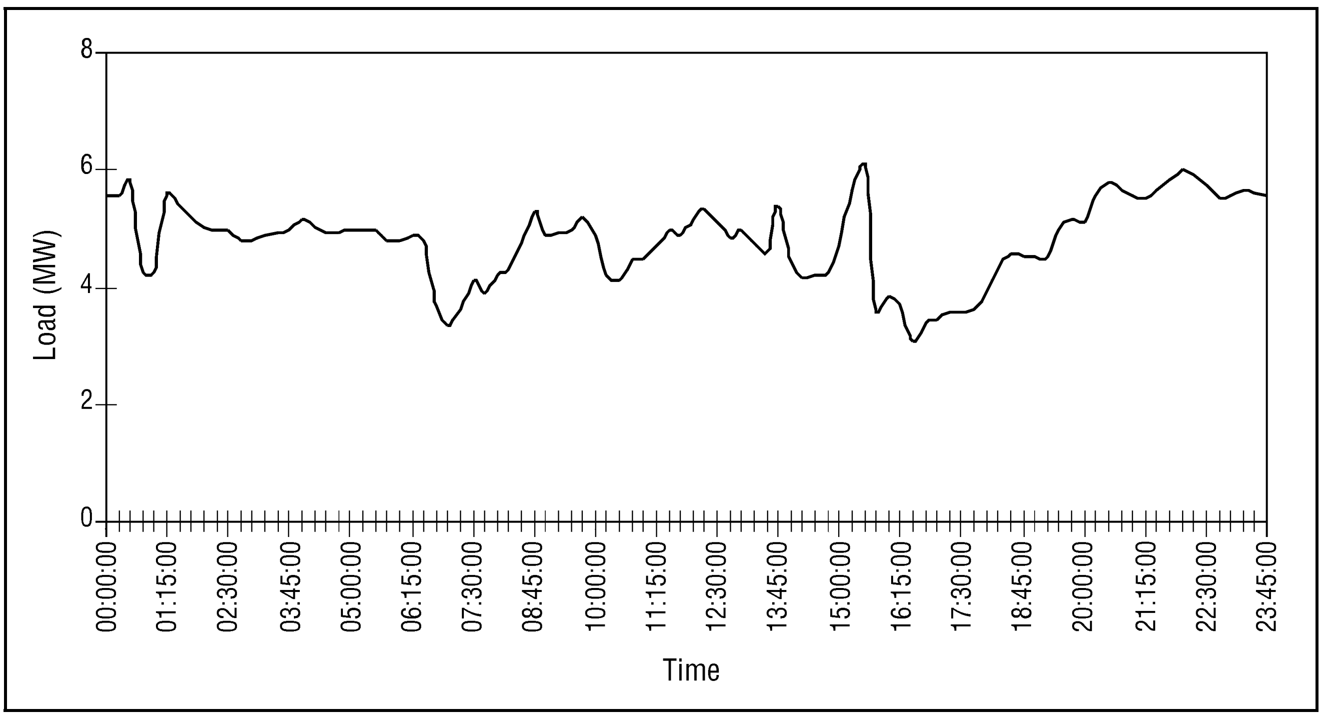

Figure 3c. Daily load demand curve for low-grown tea region
Source: Dhanapala et al. [1998]

imply a relatively constant supply of power which will be modelled later. The harvesting interval could be adjusted, within limits, to accommodate variations in tree growth rates. However, during the rainy season, harvesting, transporting and drying of biomass could impose difficulties. This aspect needs to be addressed.

The study assumes use of the latest biomass-growing techniques – short rotation coppice (SRC) energy plantations – and dendrothermal technologies which are widely available. This is currently being pilot-tested in Sri Lanka with a further 5-year detailed scientific and economic feasibility study by the Ministry of Science and Technology. These techniques are assumed in this study to be those used in harnessing potential biomass power in the tea sector.

Short rotation coppice (SRC) energy plantations are ideal for modern energy conversion technologies. In such plantations, coppicing trees such as Glinicidia and

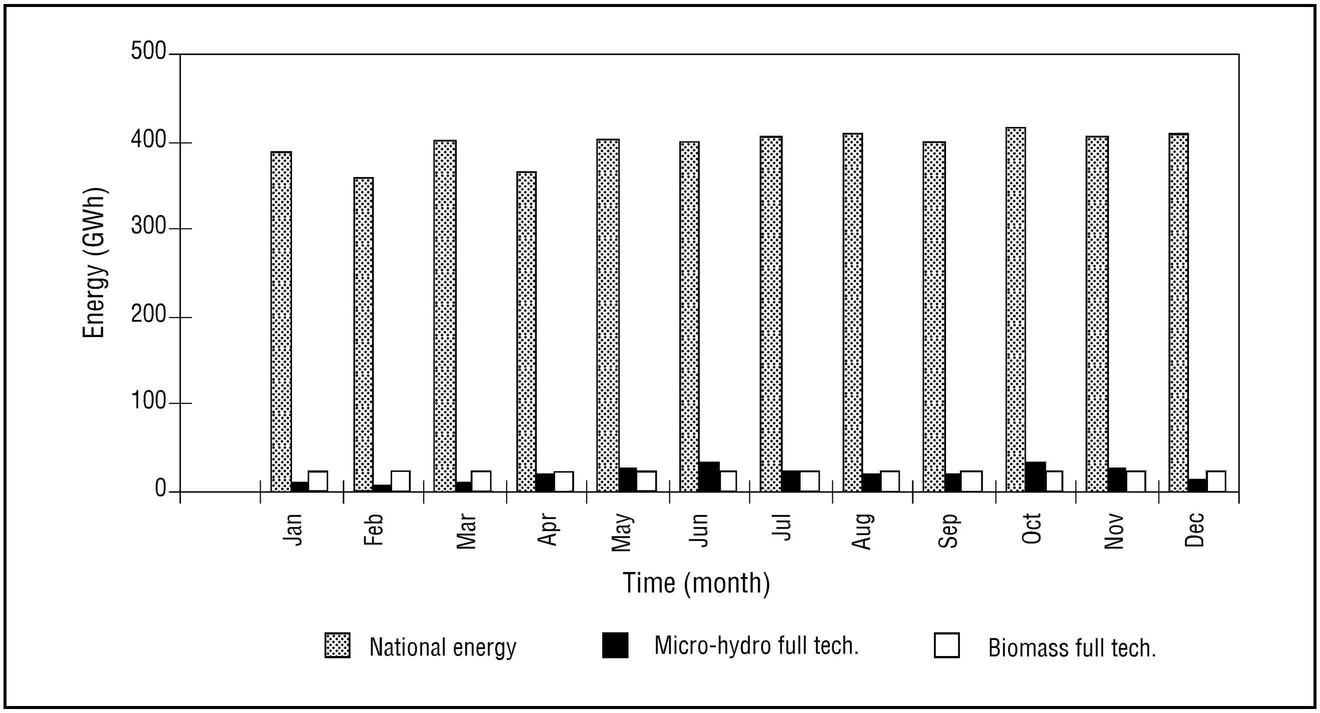

Figure 4. Micro-hydro and biomass energy supply potential in the tea sector (1997)
Source: Dhanapala et al. [1998]

Table 1. Technical potential of micro-hydro and biomass energy

	Annual energy (GWh)
Micro-hydro	
Upcountry	144.593
Mid-country	94.646
Low-country	3.921
Total	243.366
Biomass	
Upcountry	135
Mid-country	94
Low-country	26
Total	256

Leucenea casuarina are planted at high density, (such as 1 m × 1 m spacing) and the mature stems are harvested at short intervals such as 6 months to 1 year. After each harvest, new shoots develop and grow to be harvested again after the specified interval.

Technology suitable for energy generation is a harvest gasifier and internal combustion engine system. An alternative option of a steam boiler with turbine is unsuitable because of much higher capital cost requirements. The gasifier-engine system is the preferred choice for the 100-500 kW electrical power range on the basis of current technological know-how.

Technical estimates of both micro-hydro and biomass resources in the tea sector in Sri Lanka may be summarised as in Table 1 [ADB-GOSL, 1993].

5. Estimation of environmental and economic impact

The environmental and economic impact of the use of micro-hydro and biomass potential in the tea sector is investigated using four scenarios, each subject to two possible cases [Dhanapala et al., 1998].

Case 1: The available potential of micro-hydro or biomass is used only in the tea sector and any excess energy is left unutilised.

Case 2: The excess electrical energy from micro-hydro and biomass-based generation is fed to the national grid.

Four scenarios are based on the arrangements through which the energy requirements of the tea sector can be satisfied with/without the two renewable sources, micro-hydro and biomass.

5.1. Scenario 1: Base case, electricity supply with national grid only

The base-case scenario is based on the generation expansion plan of the Ceylon Electricity Board (CEB) in which only large-scale conventional generation systems are considered for future generation expansion. In this case the total tea sector electricity demand is expected to be supplied by the main grid involving large-scale hydroelectric and fossil fuel-based generating plants.

5.2. Scenario 2: Electricity supply with micro-hydro and national grid

The total potential of micro-hydro amounting to 332 GWh per year in the tea sector is expected to be exploited over a period of 15 years for electricity generation. This energy is then used within the sector while any deficit of electrical energy during certain times of the year is met by the national grid. The excess energy generated through

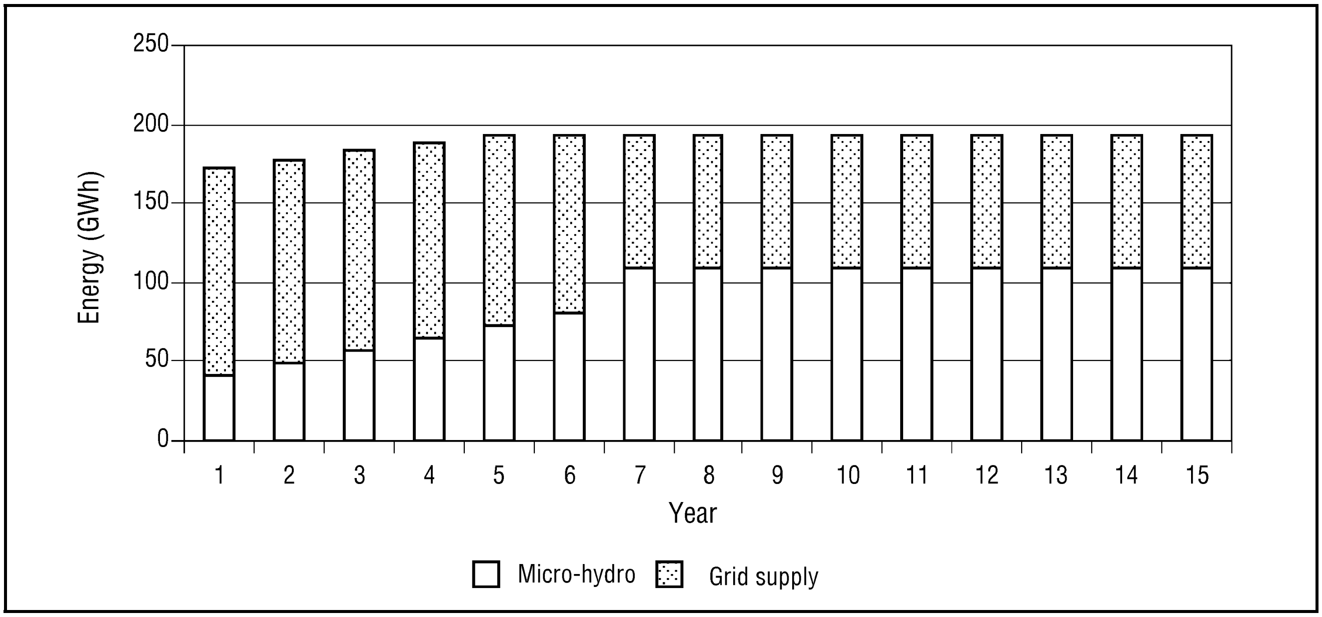

Figure 5. Micro-hydro-based electricity used only in the tea sector

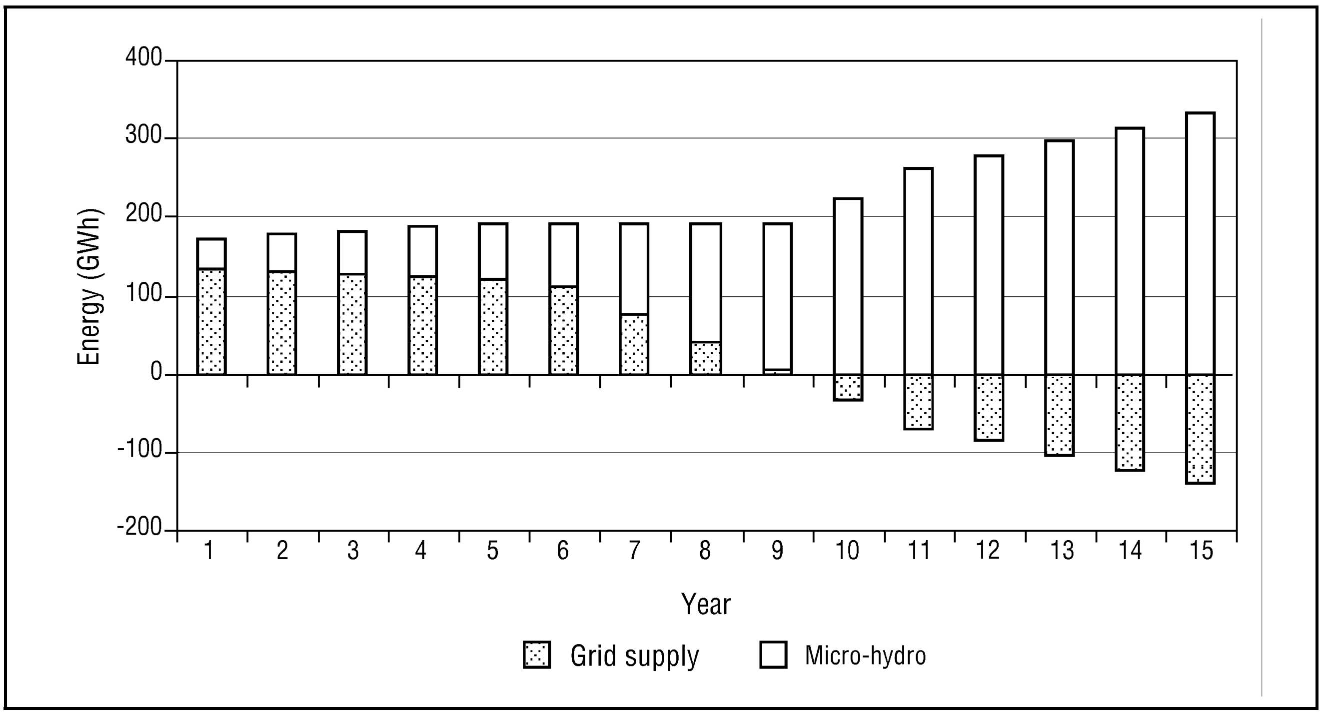

Figure 6. Micro-hydro-based electricity with excess injected into the national grid

micro-hydro at certain times is either left unused or injected back into the grid. These two cases are shown in Figures 5 and 6. The displacement of grid electricity from the tea sector or in the country as a whole by micro-hydro-based generation results in a deferment of installation of conventional generation plants. Also, part of the energy generated by these conventional systems is replaced by micro-hydro-based electricity, resulting in an overall reduction in emissions in addition to the reduction in economic costs.

5.3. Scenario 3: Electricity supply with micro-hydro and national grid, and biomass for thermal applications

The situation envisaged here is very similar to that of Scenario 2 except that the use of biomass for thermal applications is considered. Though the electrical energy and plant capacity displacement against the base case are the same as in Scenario 2 the tea sector would enjoy an additional gain from environmental benefits of growing trees for biomass-based thermal applications in the tea industry.

5.4. Scenario 4: Electricity supply with national grid and biomass along with biomass for thermal applications

It is expected that the first biomass-based electricity generating plant can be operational within two years from the start while the total possible biomass-based generation amounting to 250 GWh per year in the tea sector will be in place within a period of 9 years. The biomass

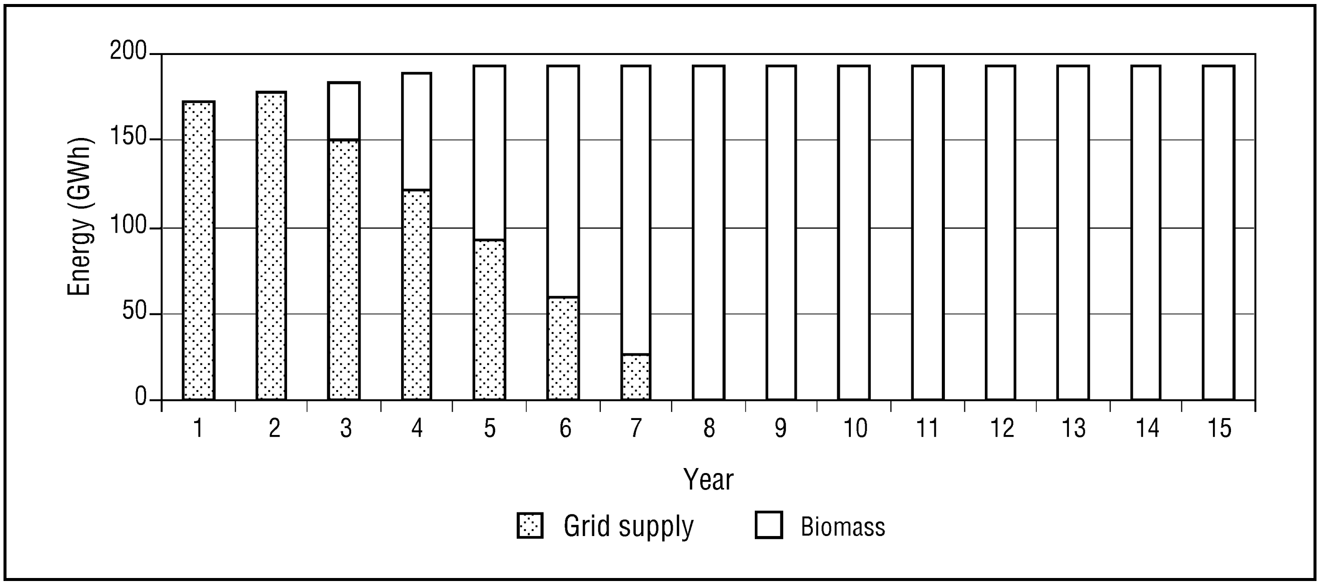

Figure 7. Biomass-based electricity used only in the tea sector

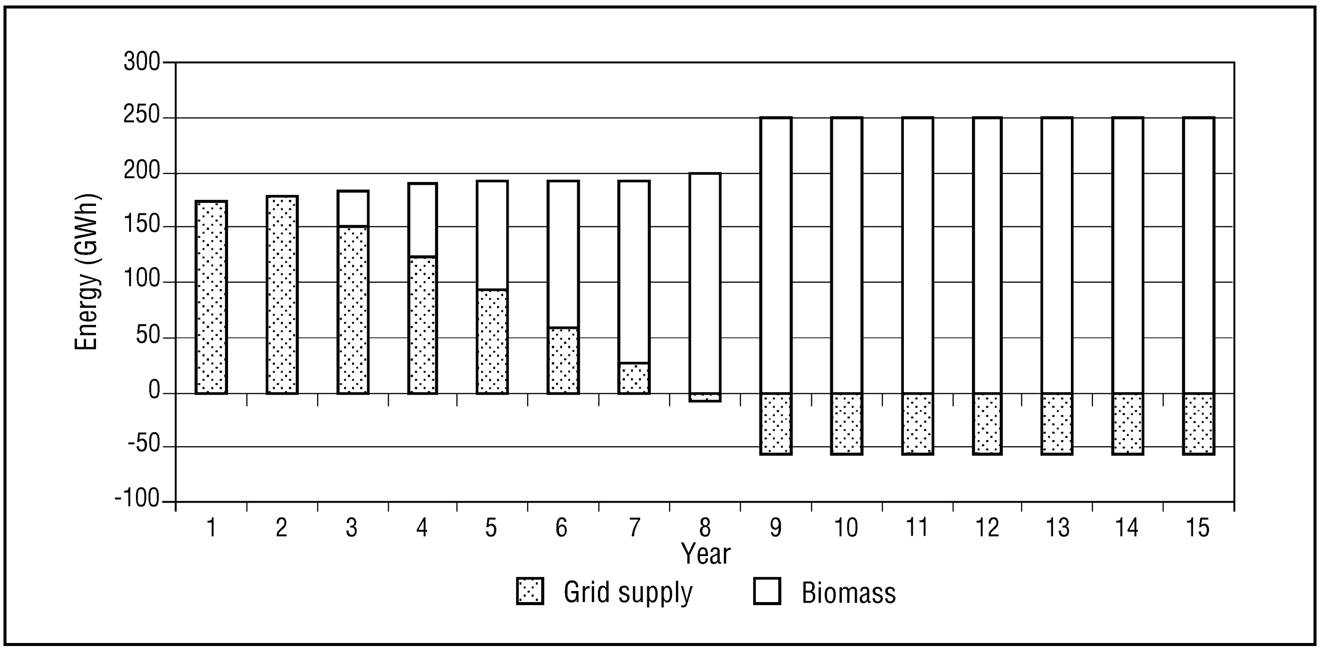

Figure 8. Biomass-based electricity with excess energy injected into the national grid

generation capacity will be such that it is either fully utilised with no excess generation or with excess energy injected back into the national grid. These are shown in Figures 7 and 8.

As in the case of micro-hydro-based generation, biomass-based generation displaces some planned conventional generation plants in the base-case scenario, resulting in reduced emissions. Also, there will be additional environmental benefits associated with fuelwood plantations supplying biomass-based generation plants.

6. Discussion

Analysis of impacts is for two cases over each of the scenarios. Case 1, or the lower-bound case, assumes energy is generated for use by the plantation sector and the surplus is not utilised. In Case 2, or the upper-bound case, such surplus energy is assumed to be sold back to the national grid, benefiting both the plantation companies and the economy as a whole. This implies greater energy supply up to the maximum technical potential and does not account for income from sales to the grid. Income from sales is not analysed at a sector level, given its factory-specific nature and fluctuations in use, supply and sale prices.

For Case 1, only micro-hydro energy costs are economically viable in comparison to the CEB unit prices. Biomass has a higher unit economic cost compared to the CEB cost but becomes cheaper if environmental benefits are also considered. While biomass is a little more expensive than grid electricity on pure economic grounds, environmental gains such as reduction in soil erosion and other environmentally damaging effects benefits the tea sector in the medium and long term onwards. In Case 2, higher productive energy use from sunk costs implies

Table 2. Economic unit costs of alternative energy generation by scenarios and case (in 1997-1998 Rs/kWh)

Description	CEB in base case		Micro-hydro		Micro-hydro + biomass		Biomass thermal + co-generation	
	Case 1	Case 2	Case 1	Case 2	Case 1	Case 2	Case 1	Case 2
Economic cost	2.80	2.80	1.57	0.98	3.93	2.45	3.36	2.89
Environmental cost	0.09	0.09	0.00	0.00	-0.85 -0.63	-2.53 -1.89	-0.53 -0.54	-1.58 -1.62
Total cost	2.89	2.89	1.57	0.98	3.08 2.73	1.39 1.47	1.92 2.35	0.87 1.27

Source: Dhanapala et al. [1998]

Table 3. Total, foreign and local economic cost components of alternative energy supply options by scenario

Energy supply scenario	Cost (1997-98 Rs/kWh)	
	Case 1	Case 2
1. CEB in Scenario 1: total costs	2.80	2.80
a) Foreign costs	1.96	1.96
b) Local costs	0.84	0.84
2. Micro-hydro in Scenario 2: total costs	1.57	0.98
a) Foreign costs	0.94	0.59
b) Local costs	0.63	0.39
3. Biomass in Scenario 4: total costs	3.36	2.89
a) Foreign costs	1.91	1.65
b) Local costs	1.44	1.24
4. Mix of biomass & micro-hydro in Scenario 3: total costs	3.93	2.45
a) Foreign costs	0.98	0.61
b) Local costs	2.95	1.84

Source: Dhanapala et al. [1998]

Table 4. Summary of unit cost differentials and benefits by scenario and case for the tea sector (in 1997-98 rupees)

Scenario	Avoided costs (Rs million)	Unit cost (Rs /kWh)
Case 1		
Micro-hydro only	885.64	1.32
Micro-hydro and biomass for thermal	926.74-2059.51	1.38-3.06
Biomass for co-generation	142.24-1,280.71	0.16-1.42
Case 2		
Micro-hydro only	2,055.89	1.91
Micro-hydro and biomass for thermal	2,097-3,230.47	1.95-3.00
Biomass for co-generation	569.34-1,702.81	0.54-1.62

Source: Study data [1997-98]

relatively lower micro-hydro unit costs and greater economic gains to the sector. Higher plant usage rates also enable unit biomass costs to fall sufficiently to allow these to be comparable with grid costs. An overview of these figures is seen in Table 2.

Further advantages associated with renewable energy supply alternatives include foreign exchange costs. Both micro-hydro and biomass each have a lower foreign cost component (estimated as about 10-13 %, although further local technological substitution is possible). A mixed option of micro-hydro and thermal use of biomass ranks first in minimising import content of economic costs (capital and O&M) which are about 25 %. The advantages of such renewable energy supplies do not include any safety equipment the national grid may require to ensure grid stability. Cost breakdowns are detailed in Table 3.

Differences in unit energy costs between the base case and other scenarios can be translated into avoided costs associated with the use of micro-hydro- and biomass-based technologies. As expected, benefits or avoided costs associated with Case 2 are more than those of Case 1 since in Case 2 the entire micro-hydro and biomass capacity available is utilised for electricity generation, without being wasted or "spilt". Therefore total national economic and environmental benefit using micro-hydro and biomass technologies in the tea sector varies from Rs 927 million to Rs 3,343.07 million during the period of 15 years. These benefits are summarised in Table 4.

7. Conclusions

The findings of the study provide one of the most comprehensive and relatively accurate estimates of selected renewable energy sources in Sri Lanka's tea sector. This is built on existing primary data sources (for micro-hydro) and secondary data (for biomass, using land estimation). Aggregate annual energy from these two supply sources is about 588 GWh.

The study discussed in the paper leads to the following conclusions

- Micro-hydro energy is the most cost-effective option to meet the electricity demand of the tea sector, particularly given its availability in this area of the country and its relative costs.
- Micro-hydro energy has the added advantage of being environmentally friendly with no other added

quantifiable costs.

- Biomass can be considered as a second and third best option only. However, there are the added advantages of relatively higher labour requirements, particularly in the cultivation of biomass plantations.
- National grid energy has higher economic costs associated with its use by the sector, given its siting, than other cost-effective supply sources, compared with its use in many other industries. Its use can be recommended as complementary or as a secondary rather than primary energy source.
- Use of national grid electricity by the tea sector is likely to become increasingly unattractive to the economy as increasing amounts of thermal capacity are added to the generation mix as is planned in the medium-term national electricity generation plans. This will be for two reasons: (1) grid electricity tariffs are likely to rise to allow for capacity additions; and (2) environmental costs associated with thermal power systems will rise.

The economic and environmental impact from the use of renewable energy sources is proven for a particular sector of the economy, the tea-processing sector, in this study. The benefit is in the region of millions of Sri Lankan rupees. Harnessing such resources, however, requires addressing far more significant and complex issues at policy level. ■

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Note

1. According to the ILO Workshop on Productivity Improvement (Colombo, April 1994).

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