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Impact on climate change from using fuelwood biomass as a source of energy and the sustainability of tea industry

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ABSTRACT: Tea is one of the most popular beverages enjoyed by the world population. Sri Lanka grows tea, processes, and markets it as 'Pure Ceylon Tea' in the international markets, and about 10% the country's population depend on the earnings of this sector. Less reliance on imported fuels and national electricity grid can help the economy of the country. As tea is an agricultural crop, climate change has a direct impact on tea plantation. On the other hand, energy is a vital input in tea production and therefore energy is a component in the cost of production of tea. Fuelwood biomass is one of the main energy source currently used and itis a potentially strong candidate to meet the energy demands of this industry. Under this context, theimpact on climate change from using fuelwood biomass as a source of energy and the sustainability of tea industry in Sri Lanka was investigated by looking at the consumption of different forms of energy in tea processing and associated greenhouse gas emissions. Fuelwood biomass is already extensively used in tea processing while electricity and fuel oils being the other major energy sources used. The energy intensive operations of withering and drying in tea processing can have a higher stake from fuelwood biomass. While tea is grown in different parts of the country by Tea Smallholders as well as Regional Plantation Companies (RPCs), there are clear differences in the average values of different parameters such as of specific energy consumption to produce a kg of made tea, GHG emissions, and cost of production across the different regions and the type of ownership. Sustainably grown fuelwood biomass as a source of energy and energy efficiency improvements in the industry can reduce the associated greenhouse gas emissions. There are many species that could be grown as purpose-grown dedicated energy plantations. Effective use of sustainably grown fuelwood biomass can significantly contribute towards economic, environmental, and social sustainability.

Key words: Tea, Fuelwood, Biomass, Energy, Climate Change, Thermal, Electrical

I. INTRODUCTION

Tea is one of the most popular beverages around the world (Sharma, 2019). Sri Lankan tea, branded as Pure Ceylon Tea, is recognized all over the world for its premium quality. Sri Lanka is the fourth largest tea producing country, and the second leading black tea exporter in the world (Gamage & Wickramaratne, 2020). However, during the recent years, falling international tea prices and rising costs of tea production have made its market highly competitive (Munasinghe et al., 2017). In the year 2019, Sri Lanka had a tea plantation extent of 200,000 ha and produced 300 million kg of tea, from which 293 million kg were exported generating an export earning of LKR 240.6 million, with a value addition of 0.7% of GDP from tea growing (CBSL, 2020_b). The main types of tea produced in Sri Lanka are orthodox, CTC (Crush, Tear, Curl), and instant tea, and their contributions during January - September 2020 were 182.4 (91%), 17.3, and 1.4% respectively (MoP, 2020). Over 2 million people, i.e. nearly 10% of the total population of the country, depend on the tea sector earnings. Therefore, the tea industry with sustainable initiatives is a prime national priority (ETP, 2019).

Objectives of the Study

The objective of this study was to review the impact on climate change from using fuelwood biomass as a source of energy and the sustainability of tea industry in Sri Lanka by looking at the greenhouse gas emissions associated with energy consumption in processing of tea.

The Boundary

The study investigated into the GHG emissions associated with the energy consumption in the tea processing factories, with emphasis on energy consumption in differentoperations of processing using fuelwood biomass as a source of energy in Sri Lanka. Accordingly, from one hand, the processes related to cultivation, packaging, distribution, sales, use, and disposal are purposely omitted, and on the other hand, supply chain of fuelwood biomass upto the factory, use of other sources of energy inside the factory, and energy used for activities other than manufacturing process of tea are excluded.

II. METHOD AND MATERIAL

The study area pertains to the whole of the country, Sri Lanka. A structure was developed to guide the collection of data to contribute to the objective of the study. Data for this work was then obtained from literature already available especially from the multiple disciplines of energy consumption, tea plantation, climate change, sustainability, power generation, and national economy. The data was then subjected to critically analysis and presented through a collation and synthesis process.

Power Sector

Sri Lanka's electricity sector heavily depends on carbon intensive primary energy sources. These carbon intensive sources contributed to 66% of the total electricity generation in 2019(CBSL, 2020).. The CO_2 emission factor (total quantity of emissions by the power sector divided by the total number of electricity units produced during the year) from national electricity grid was 585g CO_2 per kWh in 2017 which translates into 8.6 million metric tonnes of CO_2 emissions due to electricity generation during the year (SLSEA, 2019). This is an increase of 85% within 7 years. Tea processing consumes electricity, and each unit of electricity consumed in this process lead to GHG emissions which can be estimated in proportion to the grid emission factor related to the year related to their electricity consumption from the national electricity grid.

Fossil fuel is imported into the country. As a result, higher dependency on fossil fuel for electricity generation has a major bearing on the trade balance and the exchange rate. In 2019, Sri Lanka reported a trade balance of United State Dollars (US$) million -7,997 (negative) while the average Sri Lankan Rupees (LKR): US$ exchange rate was 178.78 (CBSL, 2020). Higher dependency on fossil fuel based power generation and the tea processing consuming more electricity from the national grid would therefore can contribute to widening the trade balance and weakening the LKR against US$. At the same time, if the cost of production of tea could be curtailed including from reduced consumption of electricity and fossil fuels, Sri Lankan tea can become more competitive in the international markets leading to higher foreign exchange revenue generation impacting positively on the trade balance and the exchange rate by narrowing the trade deficit where exporting of tea would make a noticeable contribution to her trade balance and stability of exchange rate.

Sri Lanka's power generation is dominated by the state owned Ceylon Electricity Board (CEB) supported by the independent power producers. Generating electricity using fuel oil is the most expensive source of power generation for CEB. Their average purchase price from the independent power producers of LKR 26.47 per kWh exceed the average tariff charged from the overall consumers of LKR 16.62 per kWh and the average tariff of LKR 14.72 applied to the industrial sector whereas the cost to CEB at the selling point on average was LKR 23.29 per kWh in 2019 (CBSL, 2020). Consuming more electricity from the national grid can therefore lead to CEB to widen deficit in their income over expenditure and become a burden to the state.

There is a clear indication of detrimental results with more use of electricity in the tea industry from the GHG emission perspectives, business viability of the state owned power utility CEB, and the national economy from the perspectives of maintaining a sound trade balance and foreign exchange rates. Switching into sustainably sourced fuelwood biomass in the tea processing could make a considerable impact to ease these situations while reaping many other sustainability benefits from economic, social, and environmental arenas.

Tea Plantation

Tea (Camellia sinensis (L) O. Kuntze) has first been introduced to Sri Lanka in1839 with a batch of tea seeds been planted at the Royal Botanical Gardens at Peradeniya. Then, in 1867, James Taylor undertook the first commercial tea plantationon 19 acres of land on Loolecondera Estate, Hewaheta (Nathaniel, 1986 as cited in FAO, 2016), which is now expended into 14 administrative districts (out of 25 in the country). The tea industry in Sri Lanka is classified into 2 main production systems based on the scale of their operations namely, the smallholdings sector which is defined as a tea land extending upto 10 acres (that is 4 ha)and the plantations sector (ILO, 2018). About 58% isin the hand of tea smallholders and the balance is managed by the Regional Plantation Companies - RPCs (FAO, 2016). The tea cultivation areas are mainly classified into 3 regions, high grown, medium grown and low grown depending on the elevation above the mean sea level. There were 722 registered tea factories in

Sri Lanka who process green tea leaves into finished products, which produced 300.0 million kg of tea at an overall average cost of production of LKR 483.79 in the year 2018 ($CBSL_b$, 2020), details of which are presented in the Table 1.

Elevation Category	Elevation (metres above mean sea level)[#]	Factories in Operation (2018)[##] (Total 722)	Production (million kg) (2018)[##] (Total 300.1)	Average cost of production (LKR/kg)[###]
High Grown	Over 1,200	170	63.1	190
Medium Grown	1200-600	133	47.2	159
Low Grown	Lower than 600	419	189.9	154

Table 1: Tea production and cost of production
Sources: Wijeratne, 2017[#], CBSL 2020_b[##], Munasinghe et al., 2017[###]

Tea smallholdings is the largest contributor to Sri Lanka's national tea production (Perera, 2014; Munasinghe et al., 2020).In the year 2015, the extent of tea smallholdings was 121,740 hectare, where tea was grown by 392,979 tea smallholders. The production of tea smallholdings was 239.86 million kg, contributing 73% to the national production recording a general productivity of 2,059 kg of made tea per hectare (TSHDA, 2016).

Energy Consumption in Tea Production

Tea processing is energy intensive as the various stages of tea production consume energy where energy costs constitute around 30% of the total tea processing costs (Sharma et al., 2019). The main stages of tea processing are withering, rolling, fermenting, drying, sifting and sorting, and packaging. These often involve a combination of electrical, thermal, and mechanical energy including labour. The main sources of energy used in tea processing in Sri Lanka are biomass, purchased electricity, and diesel (Vidanagama & Lokupitiya, 2018). Electrical energy is used in the operation of machineries and the thermal energy is applied for the reduction of the moisture content of the green leaves from about 70% to 80% down to 3%. Thermal energy is mainly generated from fuelwood, coal, briquetted fuel and furnace oil (Munasinghe et al., 2017). Typically, the withering operation consumes the highest proportion of energy in the tea processing followed by the rolling and dryingoperations. Biomass is the major energy source used in generating hot air required in the tea production process. For running the motors and for lighting, electricity is used. Amongst the electricity uses, the trough fan motors in the withering process and the maceration machines account for a major share of electricity consumption (ETP, 2019). The energy balance of a typical tea factory is given in the Figure 1.

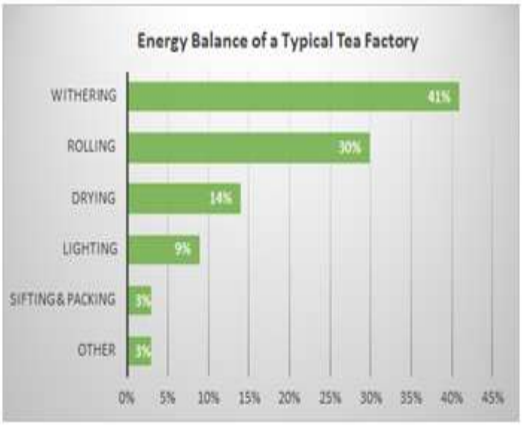

Fig 1: Energy Balance of a typical Tea Factory
Source: ETP, 2019

Withering and drying of processed tea leaves (dhool) require clean odourless hot air which is generally supplied from fuel combustion (using biomass or oils) and transferred to processing air through heat exchangers (Koneswaramoorthy et al., 2004). The moisture content of fuelwood used varies from 25 to 45% and depending on this, fuelwood demand for tea processing varies from 1.8 to 2.2 kg fuelwood per kg of made tea at fuelwood moisture contents of 25 to 35% respectively (Silva, 1996). Energy consumption, especially in the withering process can vary according to climatic conditions, the quantity and the quality of plucked tea leaves and the spreading conditions of green tea in the trough etc. (Munasinghe et al., 2017).

Drying is done to stop the fermentation and to bring the moisture level down to required 3% level. Fuelwood is the major source of energy used for tea drying in Sri Lanka (Hitinayake et al., 2018). Different types of dryers are used in tea manufacturing and the drying temperature recommended vary depending on the type of dryers as well as type of processing. Obtaining the rated dryer output whilst minimizing the energy use is one of the main challenges in processing. In most tea factories, both hot air generation and utilization and the dryer operations are performed manually. Due to this, energy wastage in tea drying operation of the tea industry vary between 0.56 kg and 3.23 kg of fuelwood per kg of made tea. With the implementation of energy efficiency improvement measures, there is a potential for the tea factories to achieve the best energy performance level where the corresponding total annual saving in the tea sector wouldthen be 42,300 tons of fuelwood. (ETP, 2019), contributing to reduction in the cost of production and related GHG emissions.

The operating temperature range and specific thermal energy consumption ofwithering and drying processes in Sri Lanka, where fuelwood mass is extensively used are presented in the Table 2.

Process	Operating Temperature Range	Specific Thermal Energy Requirement (MJ per kg of made tea)
Drying* (conventional endless chain type drier)	Inlet: 94-100^{0}C and Exhaust: 50-55^{0}C	11.0
Withering	Minimum of 2.5^{0}C difference between Dry Bulb & Wet Bulb temperatures	5.6

Table 2: Operating Temperatures & Thermal Energy Requirements for Tea Drying & Withering

Note* commonly used types of dryers are Conventional Endless Chain Pressure, Fluidised Bed and Combination of these two

Source: Koneswaramoorthy et al., 2004

The total specific thermal energy consumption for tea production varies between 4.45 and 6.84 kWh per kg of made tea. In Orthodox tea production, the withering and rolling processes consume more energy. The CTC process consumes more electrical energy. Drying needs higher temperatures than for withering (Munasinghe et al., 2017).

There are regional differences in energy consumption within the tea sector (Dhanapala & Wijayatunga, 2002). The mean specific biomass energy consumption by the up and mid country tea industries in Sri Lanka was 2.02 kg of biomass per kg of made tea with a standard deviation of 0.49 and a range of 1.66 kg of biomass per kg of made tea respectively, with a minimum recorded specific biomass energy consumption being 1.53 kg of biomass per kg of made tea. Accordingly, SLSEA set the specific biomass energy consumption benchmark of 2.02 kg of biomass per kg of made tea for this sector of the industry. The mean electricity and diesel consumption per kg of made tea were 0.78 kWh and 0.006 litres respectively while the benchmarks set and best achievements for these two sources were 0.78 and 0.57 kWh and 0.007 and 0.004 litres respectively per kg of made tea. The mean specific (overall) energy consumption was 35.2 MJ per kg of made tea and the set benchmark was 27.3 MJ per kg of made tea (SLSEA, 2016_b).

The total average energy consumption are 118 MJ per kg of high grown tea, 158 MJ per kg of medium grown tea and 108 MJ per kg of low grown tea considering lifecycle, and value chains and supply chain from plantation to disposal. The use of fuelwood biomass are 31, 67, and 20MJ per kg of tea in the high, medium, and low grown regions respectively. Accordingly, the carbon emissions by the overall tea sector and for the emissions due to use of fuelwood in the tea processing are 37.0, 35.3, and 34.3 and 0.32, 0.89, and 0.57 kgCO2e per kg of tea respectively related to high, medium, and low grown regions (Munasinghe et al., 2017). The net carbon balance for these regions from the tea sector are 0.444, 0.944, and 0.750 tonnes per year (Costa et al., 2015). The details are given in the Table 3.

Elevation Category	Average energy use (MJ per kg of tea)$^\$$		Net Carbon Balance (million tonnes per year)$^{\$\$}$	Carbon emissions (kgCO2e per kg of tea)$^\$$	
	Total	Processing (Renewable / Fuelwood)		Overall	Processing
High Grown	118	31	0.444	37.0	0.32
Medium Grown	158	67	0.944	35.3	0.89
Low Grown	108	20	0.750	34.3	0.57

Table: Energy use and Carbon balance & emissions

Sources: Munasinghe et al., 2017[$]; Costa et al., 2015[$$]

The average cost of production of tea in 2019 was LKR 489.79 per kg (CBSL, 2020b). Out of the total processing cost of LKR 60 - 80 per kg of tea, cost of energy in producing tea varies between LKR 20 - 30 per kg (ETP, 2019).

Fuelwood Biomass use in Tea Processing

Tea industry is the largest industrial consumer of fuelwood (Ediriweera & Bandara, 2020). Sri Lankan tea factories 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 come from rubber plantations (Dhanapala & Wijayatunga, 2002). Different types of biomass consumed by the tea industry are fuelwood, sawdust, paddy husk, and coconut shells (SLSEA, 2016*), as given in the Table 4.

Type of Biomass	Quantity (Metric tons)
Fuelwood	705,000
Sawdust	42,000
Paddy husk	24,000
Coconut shells	1,000

Table 4: Different types of biomass used by tea industry

Source: SLSEA, 2016* based on data from Sri Lanka Tea Board, 2013

Fuelwood with 25% to 30% moisture is suitable for use in the tea processing. However, the fresh logs (green logs) as-received would generally come with moisture level of 40% - 60%. Use of wet fresh logs in the furnace are inefficient because a significant amount of energy contained in the fuelwood would be consumed to remove the moisture in them. As a matter of fact, even if the fuelwood is stored under a cover, the moisture level in them would hardly stay below 25%due to the high humidity levels in Sri Lanka (ETP, 2019). Accordingly, the moisture content in biomass fuelwood used in tea processing has a direct bearing of the process energy efficiency and related GHG emissions.

Fuelwood Biomass Species used

From a census carried out from 2007-2008 of all the estates managed by the regional plantation companies, of the total area of tea lands, only 67% was cultivated. The land area under fuelwood or timber was 19,000 ha which is 11.2% of total land area and 16.1% of total cultivated area (Samansiri et al., 2011).

Main species of fuelwood used in Sri Lankan tea industry are Calliandra calothyrsus, Eucalyptus grandis, Paraserianthus falcataria, Hevea brasiliennsis, and Gliricidia sepium. These species possess characteristics that are typical of fuelwood species such as high growth rate, high calorific value, high coppicing ability, low leaf: stem ratio, and also good burning properties (NAS, 1980; Gunasena and Pushpakumara, 1998 as cited by Hitinayake et al., 2018). Characteristics of some of these species and others are given in the Table 5.

Species		Average wood Production (m^3/ha)	Calorific Value (kcal / kg)	Land extent by 2019 (ha)	Climatic region in Sri Lanka
1	Calliandra calothyrsus	15-50	4,500-4,750	50	Mid &high elevations
2	Eucalyptus grandis	40-200	4,700 – 4,800	200	Mid & high elevations
3	Acacia decurrens	15-25	3,530-3,940	25	High altitudes
4	Pariserianthus falcataria	30-50	2865-3357	50	Low and mid altitudes
5	Clusia rosea	125-150	4154	150	Mid and high elevations

Table 5: Characteristics of fuelwood species

Source: Extracted from fuel wood types and usage as a source of energy, their calorific values, land extents, climatic regions, and uses from Forestry Sector Master Plan (1995-2000), as cited in Ediriweera & Bandara, 2020)

Components of tea plants are also used by the tea industry, and some of their characteristics are provided in Table 6.

#	Component of Tea plant	Moisture Content %	Ash Content %	Volatile Matter %	Fixed Carbon %	Gross Calorific Value (MJ/kg)
			(Moisture free basis)			
1	Removed bush mass	15.9	1.38	24.9	73.7	19.80
2	Pruning	14.2	2.17	74	23.8	22.02

Table 6: Energy related properties of components of tea plants

Source: Comparison of biomass properties with bamboo (Tested at ITI with Sustainable Energy Authority and UNIDO 2019- Sri Lanka, extracted from Ediriweera & Palihakkara, 2020)

Climate and Environment for Tea Plantation

Tea is a rain-fed plantation crop, which grows from almost sea level to about 2,200 meters above mean sea level. This is a shade loving crop, and has a wide adaptability to different climates and soils. Tea requires an annual minimum rainfall of 1,200 mm. Under the Sri Lankan conditions, a uniform distribution of rainfall throughout the year is vital for its successful cultivation. Growth of tea shoots is optimal at the temperatures between 18 - 30 °C. In order to initiate shoot extension, a minimum leaf temperature of about 21°C is necessary and the growth decreases above 35 °C. Further, long sunshine hours are essential for the maximum yield, and dormancy sets in when the day length falls below 11 ¼ hours (Wijeratne, 2017). A wetter and hotter climate will have negative effects on Sri Lankan tea production. The changes in the rainfall, temperature and the occurrence of extreme weather events have affected the tea sector adversely, and it is predicted that annual tea production would be declined by 12% by mid-century under a high emissions scenario (Gunathilaka et al., 2017). Accordingly the tea cultivation highly depends on the prevailing weather conditions, and is extremely sensitive to both short term and long term climate variability and changes. It is reiterated that tea growth and yield are affected by many factors such as increasing temperature, excessive and high intensity of rainfall, soil water deficit and dry soil conditions, and the increases of the frequency of drought and dry spells. The excessive rainfall and high temperature can cause to lower the productivity and lower the quality of the tea and lead to lower profitability of the tea industry (Wijeratne, 2017; Nianthi, 2019).

Wijeratne et al., (2007) assessed the impact of climate change on productivity of tea plantations in Sri Lanka who confirmed that optimum temperature for cultivation of tea to be about 22 °C, and while the optimum rainfall for tea cultivation varied from 223 - 417 mm per month, the reduction of rainfall by 100 mm per month would result in a reduction of productivity by 30 - 80 kg of made tea per hectare per month in different regions as the reduction in rainfall reduces the yield in all tea growing regions. Further, an increase in ambient $C0_2$ concentration from then current level of around 370 ppm to 600 ppm, will increase tea yield by about 33-37%, but this effect is to nullify by high temperatures at low elevations. When it comes to projections for the year 2050, increasing temperatures are likely to reduce tea yields in some regions while increasing the yield in another region.The tea yields are likely to increase at high elevations due to climate change while the productivity of tea plantations at low elevations are likely to be reduced (Wijeratne et al., 2007).

Sri Lanka tea industry can be considered as a net carbon absorber having an annual net absorption of 7.837 million tonnes of CO_2 considering its cultivation and manufacturing processes. In the up, mid and low country regions, the annual carbon net absorptions were 0.874, 1.278 and 1.426 million tonnes respectively. The corresponding annual carbon emissions were 0.430, 0.334 and 0.677 million tonnes. Accordingly, the net annual carbon balances of these regions were 0.444, 0.944 and 0.750 million tonnes, making up a total of 2.137 million tonnes of carbon balance per year (Costa et al., 2015).

Considering the influence of climatic, topographical and soil factors on suitability of agricultural land for tea cultivation in Sri Lanka, 2.5% of the lands are very highly suitable, followed by 13.9% of lands being highly suitable, and 12.4% being moderately suitable, most of which are currently tea-growing areas (Jayasinghe et al., 2019). It is projected that there would be a decline in land areas suitable for tea growing by 2050 - 2070. From the currently optimally, medium and marginally suitable areas for tea growing, declines of 10.5%, 17%, and 8% respectively are anticipated, and most of the optimal and medium suitability areas in the low elevation areas are projected to be lost to a greater extent in comparison to the high elevation areas by this time. It is also projected that tea would have a negative effect on habitat suitability due to changes in the climate. This may result in the tea cultivation to shift in such a way that tea may or may not grow in some of the currently tea grown areas unless suitable adaptive measures are implemented (Jayasinghe & Kumar, 2019).

Ratnapura District has the largest number of tea smallholders in Sri Lanka where theclimate has been changing in this region which is highly vulnerable to natural disasters and other negative impacts of climate change. There is a significant increasing trend in daily maximum temperature together with an apparent trend in precipitation, with an increasing trend inconsecutive wet days (Navaratne et al., 2019). Further, some of the marginal small tea farm holders have biophysical constraints such as slopes of the land and rocky soil which force them to marginalise or leave part of their land uncultivated. (Palihakkara et al., 2015), which also can be affected by climate change.

Energy related GHG Emissions

Total carbon emissions from the tea industry in Sri Lanka is approximately 32 kg CO_2e per kg of tea, and this sector contributes 0.708 million tons of CO_2 emissions annually due to fuel consumption, furnace oil and fuelwood being the major thermal energy sources in tea production of Sri Lanka. Tea processing stage consumes the highest share of energy of a tea factory (Munasinghe t al., 2017). Electricity consumption contributes to 63% of the GHG emissions at the processing stage followed by 23% by fossil fuels and 14% by biomass (Vidanagama&Lokupitiya, 2018).

Withering and drying operations are the main contributors to GHG emissions in the processing of tea. Processing operation has a low percentage of emissions even though it has a high percentage of energy usage as most of the energy used of this operation is fuelwood. In this operation, low grown orthodox tea is the most efficient in terms of energy use and carbon emissions (Munasinghe et al., 2017).

Contribution of Fuelwood Biomass to Sustainability

Most tea factories continue to use fuelwood for their processing which is a source of renewable energy. Therefore, the energy use in the tea processing stage, despite being high, can be considered as sustainable, provided that the fuelwood is harvested in a sustainable manner (Munasinghe et al., 2017). Since purpose-grown biomass and agricultural waste are considered as sustainable sources of energy, the United Nations Framework Convention on Climate Change (UNFCCC) has recognized the net emission of sustainable biomass utilization process to be zero (ETP, 2019). Sri Lankan National Standards on Sustainably Grown Fuelwood (SLS 1551:2016) which aims to promote the sustainable production of biomass could be adopted voluntarily by fuelwood producers or users who are concerned about the sustainability of their fuelwood supply chains, and they can seek a sustainability certification auditable by an independent third party (SLSI, 2016; Musafer, 2020). This is a clear case for contribution of tea processing from an environmental sustainability perspective.

The main motive of tea plantation sector to move into biomass utilization is attributed to the reduction of energy costs. This industry has been using furnaces run on fuel oil in the past, and realized that oil prices were always rising, and their control was beyond the factory owners or the government resulting in a major impact on the cost of production. As a result, Ceylon Tea had to face severe competition. However, subsequent switching into biomass based thermal energy generation has brought a significant reduction in expenditure for energy generation (Dassanayake, 2012).This is a clear case for contribution of tea processing from an economic sustainability perspective.

RPCs claim that they encounter considerable financial constraints as a result of lower labour productivity. One of the main reasons behind this low labour productivity is the lower level of estate community's social development which apparently impacts on their abilities and, eventually creating negative effects on their productivity confirming that poor social conditionshave adversely affected the labour productivityof estate workers (Dishanka & Ikemoto, 2013 and 2014). This directly impacts on their incomes and social wellbeing. When it comes to the tea smallholder subsector, it is predominantly a part of the informal economy in Sri Lanka. This sector does not extend a social security coverage to its workers. Accordingly, there are no health schemes, statutory pensions, or insurancein operation for them. Further, their working conditions provided in the workplaces are not satisfactory as the facilities on resting rooms, first aid, maternity protection, and childcare are at a minimum (ILO, 2018). For instance, the average technical efficiency of tea smallholdings sector in Ratnapura districtwas recorded as 87%leaving a margin of 13% for further improvements through better use of available resources and technology (Jayakody and Dishanka, 2019).Lower cost of production due to efficient utilization of fuelwood biomass as a production inputs, and thereby ability in increasing the profitability of the sector indicates a clear case for contribution of fuelwood biomass in tea processing from a social sustainability perspective, particularly considering the fact that there are over 2 million people, i.e. nearly 10% of the total population of the country depending on the tea sector earnings.

III. DISCUSSION

Unreliability of the biomass suppliers is a main challenge encountered by the tea industry who are encouraged to switching to biomass-based energy generation. As a result, they focus on moving to energy plantations (Dassanayake, 2012) to support their tea factories. The average growing cycle of energy plantations is 8 - 10 years, and the average annual yield is 12 - 20 tons per ha of most of the species grown for the purpose of fuelwood by the plantation sector (Samansiri et al., 2011). Further, the fuelwood trees which are planted at altitudes over about 1,500 meters (5,000 feet), mostly eucalypts, cannot be harvested because of environmental regulations. The approval process is long and complicated and may take even over a year to harvest the trees planted below this elevation. Therefore, the plantation companies prefer to purchase their fuelwood requirements for the tea factories from outside sources (ADB, 2016).

Gliricidia is a nitrogen fixing crop widely grown all over Sri Lanka which is often used as a fuelwood. This is also commonly grown in hedgerows along the contour lines in sloping landsand continuous mulching with pruned biomass from hedgerows improve soil conditions while reducing erosion (Munasinghe, 2003). These trees pruned at 1.5 m of height while allowing all branches to grow naturally lead to a higher biomass yield of about 11.2 tons per hectare. These trees can be harvested in 5 month intervals as its regeneration potential is high at 5 months (Atapattu et al., 2017_b).For instance, Gliricidia provenance, named as Gualan which has a calorific value of 3,750 kcal per kg and moisture content of 57.9% demonstrates good fuelwood characteristics for being a fuelwood tree species. It has higher dry weight and oven dried density (88.2% and 20.3% higher than the local land race respectively) with a low ash content (26% lower than local land race) (Atapattu et al., 2017). Accordingly, Gualan is a promising Gliricidia provenance to meet thermal energy requirements.

Bamboo is a fast-growing grass which also grows in degraded lands (Sharma et al., 2018). These species have a potential to make a significant contribution to carbon sequestration (Sohel et al., 2015). Bamboo can rapidly store and sequester carbon and also has good fuel characteristics encouraging it to be used as modern source of energy. The integration of this multi-purpose perennial crop into the energy systems can contribute to achieving renewable energy targets substantially (Sharma et al., 2018) being a short rotation plant, which grows fasts and could be harvested as a renewable energy source (fuelwood) without replanting for about 3 - 4 years. Itdemonstrates vegetative propagation through different plant materials and seeds in some species. Some of its characteristics such as heating value, moisture content, ash content, chemical composition, and density makes it to perform as a fuelwood although these characteristics can noticeably vary from one fuel to another (Ediriweera & Palihakkara, 2020).

Eradication of invasive species through habitat management also involves measures such as prescribed burning following safety measures. Some such species may have to be burned in order to cease their regrowth (MMD&E, 2015). For instance, Clusia rosea, commonly identified in Sri Lanka as “Gal Goraka”, “Pulichcha”, “Ambul gas”, or “Galidda” in the local languages are found to be comparable with common fuelwood species used in tea drying, mixed upto 50% with other fuelwood. This is a suitable fuelwood species for tea drying. This tree that can grow on infertile rocky lands, can even establish on wet mosses growing on rock surfaces, has a high growth rate and a high biomass production, and using this as a fuelwood shows a significant reduction in the specific fuelwood consumption without causing deposition of latex on heat tubes by maintaining flue gas temperature above 100^0C. (Hitinayake et al., 2018).

The overall energy consumption, especially in the withering process can vary according to many factors such as climatic conditions, the quality of the plucked tea leaves and their quantity, and as to how the green tea is spread in the trough etc., (Munasinghe et al., 2017). The quantity of fuelwood required by the tea industry is also dependent upon many factors including the type of wood, efficiency of the furnace and the drier, type of manufacture and waste heat recovery system etc.,. However, the efficiency of most furnaces used in the tea industry are very low, only have 55-65% (Hitinayake et al., 2018). Given the fact that fuelwood is a major thermal energy source in the tea production and energy efficiency in the tea factories are generally low due to the use of outdated equipment and old technology (Munasinghe et al., 2017), there exists a great potential for energy efficiency improvements in the tea factories (Sharma et a., 2019), for instance, splitting and peeling are effective methods in removing moisture from fuelwood (Hitinayake et al., 2018).

IV. CONCLUSIONS

Production of tea and a sound tea industry contributes significantly to Sri Lanka from many perspectives, it being one of the major export agricultural crop that brings in foreign revenue while favouring the foreign exchange rates, and as nearly 10% of the population strongly relyon this industry. However, global warming and climate change have a direct impact on the tea industry threatening the health of the industry. Similarly, different operations in the tea industry, including processing of tea, where the plucked green leaves are transformed into finished goods, can in turn contribute to global warming and climate change.

Tea is grown in different part of the country by Tea Smallholders as well as Regional Plantation Companies. The tea cultivation areas are low grown, medium (mid) grown, and high grown. There are clear differences when considering the average values of different parameters such as of energy consumption, GHG emissions, and cost of production across the different regions based on the elevations where tea is planted (sourced by the tea factories) and the type of ownership (Smallholders or RPCs).

One of the main routes to contribute to the further development of the tea sector are the reduction in cost of production, thereby making the tea more competitive in the market and increasing of profitability of the sector brining benefits to its multiples of stakeholders. As energy is one of the main inputs in the processing of tea, reduction in energy costs can help reduce overall cost of tea production.

Energy accounts for nearly 30% of the cost of tea production.Improving energy efficiency is one of the solutions in hand to handle energy productivity and thereby reduce the required energy input. Another effective approach to overcome challenges on increasing cost of production is the use of fuelwood biomass as a source of energy, which can be comparatively economical. Externally supplied sustainably sourced fuelwood and sustainably grown energy plantations (purpose-grown dedicated energy plantations) at lower costs can contribute towards the overall economic sustainability of the tea industry. Further, nearly 10% of the country's population rely on the earnings of this sector, and any improvements to the sector can directly or indirectly bring in economic and social benefits to them.Using of sustainably grown or sourced fuelwood biomass also contributes to environmental sustainability as evidenced by the UNFCCC recognising the net emission of sustainable biomass utilization process to be zero. Adopting the Sri Lankan National Standards on Sustainably Grown Fuelwood can be a good approach to ensure sustainability and get independently assessed certification for wider acceptance.

The operations of withering and drying in tea processing can have a higher stake from fuelwood biomass. Tea is grown in different part of the country by Tea Smallholders as well as Regional Plantation Companies (RPCs). There are clear differences when considering the average values of different parameters such as of energy consumption, GHG emissions, and cost of production across the different regions and the type of ownership. Sustainably grown fuelwood and energy efficiency improvements in the industry can reduce the greenhouse gas emissions. There are many species that could be grown as purpose-grown dedicated energy plantations. Effective use of sustainably grown fuelwood biomass can significantly contribute towards economic, environmental, and social sustainability.

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