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Feasibility study on renewable energy system in tea (*Camellia sinensis*) estates of North-East India

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ABSTRACT

The management of energy consumption in agriculture is a worldwide concern because of the adverse effects of CO_2 emissions from fossil fuels, which are generally used as an energy source for various applications in agriculture. Renewable energy technologies are promoted in many parts of the world for various agriculture applications for mitigating CO_2 emissions associated with fossil fuels. Tea (*Camellia sinensis*) is the most manufactured beverage consumed in the world and the global tea market has been valued at 15 billion dollars. India ranks second (after China) among the tea producing countries across the World. A pilot study was carried out in the north eastern states of India, which is the major tea-growing region of the country during 2020. The main objective behind study was to explore the use of non-renewable sources of energy and amount of CO_2 emission from the conventional energy sources as well as the feasibility of a renewable energy system in tea estates. The results from data analysis reveal that there is huge scope for adoption of renewable energy systems in tea estates of the north-eastern region which will be beneficial both for the tea estates as well as the environment.

Keywords: Conventional energy, CO_2 emissions, Renewable energy, Tea cultivation

The world community faces two major and interrelated problems in a sustainability context, i.e. the global climate change and the economic, ecological and social problems which are faced by the developing and under developed countries too. The management of energy consumption in agriculture is a worldwide concern because of the adverse effects of CO_2 emissions from fossil fuels, which are generally used as an energy source for various practices in agriculture. Tea (*Camellia sinensis*) is the most manufactured beverage consumed in the world and the global tea market is valued at 15 billion dollars (Chang 2015). The tea crop requires a specific type of agro-climatic environment that is only available in tropical and subtropical areas. Therefore, tea production is purely limited to a few areas around the world and it is highly sensitive to fluctuations during the developmental stages of the plant. Notably, due to changes in climatic conditions around the world, its ideal growing condition is at high risk.

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Kumar *et al.* (2021) have extensively reviewed the opportunities for renewable energy technologies for meeting the energy demand of tea plantations and industry in India. One of the major activities nowadays in tea estates that require a huge amount of energy is irrigation practices. Several water-saving irrigation techniques are used in many tea plantations (Jia *et al*. 2018). Different operations other than irrigation in tea estates also utilize energy in various forms and magnitudes. In tea factories, withering and drying are the most energy intensive processes followed for tea production which requires a huge amount of heat. The heat is predominantly produced by using coal (Mitra *et al*. 2016). Increase in fossil fuel-based energy consumption contributes significantly to environmental problems both locally as well as globally. To assess the magnitude of the problem, a study has been undertaken jointly by ICAR-IASRI, New Delhi and IIT, Delhi and Tocklai Tea Research Institute (TRI), Assam to explore the amount of emission of greenhouse gases along with the cost of use of conventional non-renewable energy system and therefore the possibilities of updating of the age-old system with some modern non-polluting renewable energy systems for tea plantation.

MATERIALS AND METHODS

Indian tea is among the finest in the world owing to strong geographical indications. As per Statista online,

the main tea-growing regions in India are Assam (702 million kg in 2019) in north east India and Darjeeling district and the dooars region of West Bengal (395 million kg in 2019). Assam is the most prominent tea producing and exporting state, contributing to approximately 52% of total tea production in India. In the state of Assam, the tea industry employs more than 6.85 lakh people and this industry contributes as the major economic status to the state (Narzary 2016). There are 765 tea estates in Assam and more than 100000 small gardens covering 312210 ha, which together produce 580 million kg of tea (Economic Times 2008). Although the state is blessed with abundant fossil fuel resources, yet, its increasing demand is creating a threat to its availability in the long term.

Consequently, to create an alternate system for production of energy for cultivation and production practices in tea, present study has been conducted. Data were collected through questionnaires covering various activities involved in tea cultivation and production of tea in Assam and North Bengal in the year 2020 with the help of Tocklai Research Institute, Assam. One of the major activities nowadays in tea estates is irrigation practices. Earlier, the dependence for irrigation was very less as the rainfall had a consistent pattern. The soil of tea gardens in the mountains and hills is thin with poor water retention capacity. Coupled with the characteristics of irregular seasonal rainfall, there is often occurrence of seasonal drought in tea gardens. Hence, information on various aspects and techniques related to irrigation such as its power source and methods were collected. Additionally, data related to different cultivation practices like spraying, pruning, plucking that are followed in the tea gardens and consume considerable amount of energy and manpower were collected. Likewise, information related to the estimated production of the factory (overall as well as at each step of manufacturing) was obtained. Data related to types of fuels and its consumption rate along with different equipment and machineries used in different processes of production were received from the tea processing industries. In particular, data pertaining to different procedures involved in tea production such as withering, fermentation and drying etc. were collected. In this study, data were collected from randomly selected eight tea gardens (four from Assam and four from the northern area of West Bengal) and seven tea processing industries.

RESULTS AND DISCUSSION

The empirical analysis from primary data collected through enquiry based on questionnaires from tea gardens and tea processing industries in North-Eastern region of the country was done. The data items were collected on diverse aspects including energy use patterns in various activities of tea gardens that use extensive energy and manpower such as irrigation, spraying, pruning and plucking. These activities in tea gardens are predominantly using energy from fossil/petroleum-based fuels. The data analysis also indicated that the cultivation practices that consumes a considerable amount of energy are irrigation, mechanized pruning, tractor mounted spraying, power spraying, and plucking. In addition, some cultivation practices in the tea garden require a significant amount of manpower such as tea nursery, manuring, drain making, pruning, spraying and weed control. Tea gardens need timely and appropriate irrigation to ensure the stable yield and quality of tea. The results from analysis reveal that the average annual rainfall ranges between minimum of 1200 mm to maximum of 3380 mm with an average of 1960 mm. Further, the soil moisture is a key factor for making decisions on the time of irrigation as well as the quantity of discharge. Due to drought weather conditions, generally the irrigation in the tea garden is required during November to March. About 62.5% of irrigation is done through Canal water and 37.5% by tube-well in these regions. The sprinkler (87.5%) method of irrigation is mostly being adopted while few (12.5%) tea gardens are also using drip method of irrigation. As a main power source to drive the irrigation pump set, most of the tea gardens use diesel generator coupled with the pump (62.5%), however electricity grid and diesel generator coupled with the pump is used by some (25%) and few of tea garden (12.5%) uses electricity grid as the power source. When the power source for irrigation is the electricity grid, the garden often faces power cuts during the irrigation period. Approximately 62.5% of tea gardens experience 0-5 h of power cut per day while around 12.5% of them face 6–10 hours of power cut per day. However, about 25% of tea gardens do not experience power cuts.

Irrigation is emerging as one of the most cost-intensive process and is getting unavoidable in the gardens due to decline as well as shrinking of rainfall distribution pattern as a consequence of due to climate change. One of the reasons behind the change in climate is over use of conventional methods which use fossil fuel leading to air pollution. Hence, questions related to different alternative forms of renewable energy that can be used for cost intensive practices such as irrigation in the tea gardens were enquired. The main purpose of these questions was to get an idea of non-renewable sources of energy that can be replaced. Queries were made regarding wind speed that is observed in the gardens as well as about solar and hydro energy. Some of the tea gardens revealed that the wind speed of 5 m/s or more was recorded in April-May (25%), however few of them (12.5%) recorded wind speed in March while most (37.5%) tea gardens have no data recorded related to wind speed. Most of the tea gardens consider solar energy (87.5%) as the alternative power source other than conventional power sources like electricity grid or diesel generators, whereas few of them consider hydro power (12.5%) as an alternative renewable source of power for irrigation. For implementation of renewable energy sources, i.e. solar energy, at least one acre of unused/barren land is required for installing Solar PV Panels in the tea estates. It was found that most of the tea gardens (87.5%) have barren or unused land, however few (12.5%) say that they do not have any. Further, all of the tea gardens agreed that the installation of large solar panels within the garden will not have any impact on the

growth of tea plants while none of the tea gardens has data on solar radiation.

Analyzing the data related to annual and monthly tea production with running time of tea industries in hours per day, revealed that the annual tea production in the tea industries ranges between minimum of 6.3 lakhs kg to maximum 32 lakhs kg with an estimated average of 17.3 lakhs kg. The 95% confidence interval (95% CI) for the average estimate of annual tea production lies between 10–24.60 lakhs kg. The month-wise production of made tea in the industry ranges between 0.5–3.5 lakhs kg with an average production of made tea of 1.85 lakhs kg. The 95% confidence interval for the average production of made tea lies between 1.04–2.65 lakhs kg. The tea factories run for several hours per day to produce this large amount of tea as per their capacities. Particularly, tea processing industries run about 12–20 h/day with an average running time of 17.14 h. Tea industries use conventional fuels as a source of energy for almost all the stages of operations. Since, the major contributors of carbon dioxide emissions is electricity and heat production as compared to manufacturing and other sectors (Fathima *et al*. 2016), therefore the data related to use of electricity and conventional fuels in tea industries were collected. The information obtained from tea industries revealed that the requirement of generator sets in these industries varied from 2 to 5 in numbers. On an average of 4 generator sets are required by the tea processing industries. All the tea factories use diesel generator sets as a source of energy. Most industries use 320 KVA capacity generator sets. The capacities of these generator sets vary between 55-500 KVA depending on the nature of load of work. These industries on an average consume 38.6 l diesel/hr. In these industries mostly coal (85.71%) is used followed by natural gas (28.57%), TD oil (14.29%) and electricity (14.29%) for the producing heat during the withering and drying process of the tea.

The freshly plucked tea leaves from the gardens undergo several processes in the tea industry to obtain the end product. The different processes in the tea industry are withering, fermentation, drying, sorting and packing, all of which are energy consuming processes. Withering is the first processing step in which fresh green leaves from the field are spread on troughs and air is blown through the leaves by electric fans to remove moisture. The total withering area in the factory varies from 10560–43000 sq ft Average withering area in the factory is of 24218.14 sq ft with the standard deviation (SD) of 9177.76 sq ft. The total connected load for trough fans lies in the range of 100 Hp-456 Hp with the average load of 221.84 Hp and SD of 122.54 Hp. Most of the factories (71.43%) use aluminum or other metal type withering trough fan blades. The trough loading (kg of green leaves per sq ft of trough area) of 1.5-2.5 kg is usually maintained in the factory with the mean trough loading of 2 kg. The airflow rate of 20-40 (cfm/sq ft) is maintained in the factory with the average airflow rate as 30 cfm/sq ft. The operating temperature of the withering process in the factory ranges from 28ºC to 36ºC with the average operating temperature of 32ºC. During the process, the leaf loses surface moisture and then internal moisture to become soft for easy crushing.

Withering is followed by the process of rolling that is normally carried out in two ways, either by CTC or orthodox. CTC refers to the Crush, Tear and Curl process where the withered green leaves are passed in-between two rollers rotating in opposite directions. This leads to complete maceration of the leaves. Next, the crushed leaf is conveyed to the oxidation unit, which has electrically movable metallic strips. Aimed at oxidation of tea leaves, most of the industries (85.71%) uses continuous fermenting machine (CFM) type of oxidation system in the factory, whereas only (14.29%) uses floor type of fermenting systems. Most of the industries (85.71%) use a central humidification plant for the humidification system used in fermentation, whereas few (14.29%) industries use an spot humidifier. The operating temperatures of the fermentation process in the factory ranges from 24ºC to 30ºC with the average operating temperature of 28ºC. The process of fermentation is followed by drying. Drying is done to arrest enzymatic reaction as well as oxidation and to remove moisture from the leaf particles and to produce a stable product with good-keeping quality. Most of the factories (71.43%) use vibratory fluidized bed driers while some of the factories (28.57%) use fluidized bed driers for the drying of tea leaves. All the factories require blower fans and feed system integrated along with the drier. Additionally, some factories require hot-air duct (85.71%)-drier. Few of the factories also uses glass wool (14.29%), ceramic wool (14.29%), asbestos (14.29%) and natural fibres (14.29%) as insulating material for hot-air duct in the drier. The operating temperature of the drying process in the factory ranges from 100–125ºC with the average operating temperature of 120ºC. All of the processing industries are of the opinion that the exhaust from the drier has the potential to be recycled for withering and drying as it can minimize cost of production by saving a lot of energy. Then the dry tea is discharged from the dryer and conveyed for sorting and grading. The fractions are to be brought to the desired sizes and forms with adequate uniformity and cleanliness conforming to trade requirement.

In performing all of the above operations in the production of tea, industries use conventional sources of energy such as coal, diesel, TD oil, natural gas, etc. that generate a lot of pollution. So, a calculation has been made to find out total energy consumption per kg of tea made. Total energy can be calculated as the sum of total electricity consumed per kg of made tea, total energy consumed using coal per kg of made tea, total energy consumed using natural gas and total energy consumed using TD oil. Total electrical energy consumed using diesel (in generator sets), is included in total electricity consumed per kg of made tea. Calculations have been performed for the production of tea made per hour, considering 30 days in a month. Due to consumption of various fuels as well as diesel there is a great amount of CO_2 generated during the process.

Table 1 Summary of the total energy consumption and total CO_2 generated by the tea factories

Summary statistics	Total energy consumption (MJ of energy/kg of made Tea)	Total CO_2 generation (kg of CO_2 generated/ kg of made Tea)
Minimum	15.13	1.74
Median	22.93	2.05
Mean	33.87	2.64
Maximum	89.39	4.54

Table 2 Average size of tea gardens along with annual total diesel consumption in various tea production process

	Total area of tea garden (ha)	Annual diesel consumption (l)		
		Total	Irrigation	Activities other than irrigation
Minimum	675.35	57828.00	1885.00	54787.00
Mean	803.88	135846.57	5710.75	130135.82
Maximum	954.71	264166.45	14890.00	261139.45

Table 3 Summary on cost of diesel, energy generation from diesel and CO_2 generation from diesel consumption for tea gardens

	Annual total cost		Annual total energy generation		Annual total CO_2 generation	
	Diesel (₹/ha)	Diesel for irrigation (₹/ha)	Diesel (MJ/ha)	Diesel for irrigation (MJ/ha)	Diesel (kg/ha)	Diesel for irrigation (kg/ha)
Minimum	5685.6	156.4	3198.1	88.0	17926.7	493.0
Median	9256.4	254.8	5206.7	143.3	29185.6	803.2
Mean	10642.8	481.5	5992.3	270.8	33556.8	1518.1
Maximum	18372.7	1260.0	10357.9	708.4	57929.2	3972.9

Table 1 describes the summary statistics of the total energy consumption (MJ of energy/kg of made tea) and total CO_2 generated every month (kg of CO_2 generated/kg of made tea) by the tea industries.

Table 1 depicts the volume of CO_2 emission from consumption of fossil fuel for production of energy in the tea factories. It can be comprehended how much CO_2 is produced by these factories when an average of 2.64 kg of CO_2 generated/kg of made tea since in India every year around 580 million tonnes of tea is produced. Hence, it can be assumed how much air pollution is caused every year by these activities solely from tea factories. Table 2, enlightens the average size of the tea gardens along with their average annual diesel consumption in various cultivation practices for production of tea while, Table 3, gives a tentative idea about the cost incurred in production of tea and in due process the energy generated by burning fossil fuel and total CO_2 generated annually.

Table 3 shows that around ₹10642.8/ha is annually spent to purchase diesel for tea processing while cost of ₹481.5/ha is incurred by the same for irrigation yearly. Further (Table 2) it is clear that most of the tea gardens are of an average size of 804 ha with annual average total diesel consumption of 135846.57 l for various activities in tea production. Consequently, the magnitude of CO_2 emission solely from tea estates for production of tea is vast. This indicates an urgent need for considering the renewable source of energy as an alternative to the conventional sources. Some modern renewable energy sources like solar or hydropower can solve the issue. However, analysis of data reveals that tea estates prefer to adopt solar energy as an alternative source. This is because installation of a hydro-power station is very costly for the tea estates, whereas solar energy using solar panels are easy to install with one-time initial investment. In other tea producing countries such as Malaysia and Sri Lanka, studies have been conducted for the use of solar assisted systems for withering and drying of tea leaves. The results of these studies indicated that with the use of solar energy, a great amount of conventional fuel could be saved (Koneswaramoorthy *et al*. 2004, Yahya *et al*. 2005). These renewable systems are environment friendly and involve least maintenance cost. Hence the implementation of an alternative source of energy using solar will lead to reduction in overall greenhouse gas emission as compared to conventional fuel for generation of energy, which is going to be a better deal for both the estate owners as well as environment concerns nationwide.

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