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Harnessing Biomass Energy for Sustainable Development in India's Plantation Sector: A Comprehensive Review

Pratima Mutyala*

Abstract

This review article explores biomass energy as a sustainable solution for the Indian plantation sector, aligning with the UN Sustainable Development Goals. India aims to achieve a 500 GW renewable energy capacity by 2030, with biomass energy playing a crucial role in this transition. The plantation sector, encompassing tea, coffee, rubber, coconut and spices, is vital for India's economy and rural employment. Efficient energy use in plantations can enhance economic viability and environmental sustainability. The article discusses various biomass energy applications, including combustion, gasification, densification and carbonisation and their benefits for plantation crops. It highlights the potential of energy plantations, particularly using species like Eucalyptus and Casuarina, to address rural energy crises. Despite the environmental challenges, such as deforestation and air pollution, the article underscores the need for replanting, awareness and improved equipment designs. By implementing pilot projects, providing financial incentives, technical assistance and developing efficient biomass supply chains, biomass energy can be a significant renewable energy source for the plantation sector, promoting sustainable and equitable development.

Keywords: Biomass Energy, Plantation Crops, Sustainable Development, Environment Challenges, Policy Recommendations for Alternative Fuels, Renewable Energy

INTRODUCTION

One of the main components of the UN Sustainable Development Goals is to ensure access to sustainable, affordable and reliable source of energy for all. By the year 2030, the share of renewable energy in overall energy generation and utilisation of all participant nations needs to increase as per set targets. In line with these stipulations, India has set a target of installed capacity of 500 GW of renewable energy by 2030. As nations look for means to transition away from fossil fuels towards cleaner alternatives, new forms of energy resources are being assessed for their suitability to different sectors of economic activities (Ossewaarde, 2018). Biomass energy is one such alternative that needs to be explored.

The Government of India has taken several initiatives to reach the Sustainable Development Goals but it will be difficult without people's participation at the grassroots levels, particularly in industrial and agricultural sectors. The Plantation sector in India is a vibrant component that is directly contributing to the growth of both of these, by providing employment to hundreds of families in the north-eastern and southern parts of the country.

The National Policy on Biofuels (2018) aims to promote the production and use of biofuels, including ethanol, biodiesel and other biofuels. It expands the scope of raw materials for ethanol production to include sugarcane juice, sugar-containing materials like sugar beet, sweet sorghum, starch-containing materials like corn, cassava and damaged food grains. It sets a target of 20% ethanol blending in petrol and 5% biodiesel blending in diesel by 2030. The policy provides financial and fiscal incentives, including tax incentives to support biofuel production.

OBJECTIVE

The article aims to explore biomass energy as a viable solution for meeting India's renewable energy targets,

* Assistant Professor, Jain (Deemed-to-be) University, Bangalore, Karnataka, India. Email: pratima.vishnu@gmail.com

particularly within the agricultural sector. It emphasises the role of the plantation sector in India's renewable energy landscape, presenting case studies and fieldwork by agricultural scientists to advocate for biomass energy's potential.

METHODOLOGY

This is a comprehensive review article that integrates data from various sources, including case studies and field observations, to highlight the potential of biomass energy. It examines different biomass energy generation techniques such as combustion, gasification, densification and carbonisation and their application in plantation crops like tea, coffee and spices. The article also discusses the environmental impacts, challenges and benefits of implementing biomass energy and recommends policy measures, pilot projects, financial incentives and technical support to promote its adoption in India's plantation sector.

An Overview of Indian Plantation Sector

The plantation sector in India is a significant component of the agricultural economy, contributing substantially to both national income and export revenues. Dominated by crops such as tea, coffee, rubber, coconut and spices, this sector plays a crucial role in the livelihoods of millions. India is the world's second-largest producer of tea, with states like Assam, West Bengal and Tamil Nadu being key regions. Coffee cultivation, primarily concentrated in Karnataka, Kerala and Tamil Nadu positions India as the seventh-largest global producer. Rubber plantations, mainly found in Kerala, account for over 90% of the country's output, making India one of the top rubber producers worldwide. The coconut sector, crucial for both domestic consumption and export, sees significant production in Kerala, Tamil Nadu and Karnataka. Spices, including black pepper, cardamom and ginger are predominantly grown in the southern states and hold a vital place in global spice markets. In 2021, plantation crops contributed approximately USD 7 billion to India's export revenues, underscoring their economic importance. The sector also provides direct and indirect employment to millions, thereby supporting rural economies and contributing to the country's socio-economic development.

Efficient energy use is pivotal in the production system of plantation crops, influencing both economic viability and environmental sustainability. Energy inputs in plantation agriculture, such as electricity for irrigation, fuel for machinery and processing, represent significant costs. Optimising these inputs can lead to substantial cost savings and enhanced profitability. For instance, adopting renewable energy sources like solar-powered irrigation systems can reduce reliance on conventional electricity and lower operational costs. Additionally, energy-efficient machinery and practices, such as precision farming and integrated pest management, can minimise fuel consumption and improve yield efficiency.

The environmental benefits are equally significant, as reduced energy consumption leads to lower greenhouse gas emissions, contributing to the mitigation of climate change. Implementing energy audits and monitoring systems can help in identifying inefficiencies and opportunities for energy savings. The integration of smart technologies, such as IoT and AI, in managing energy use further enhances the potential for efficiency. Thus, prioritising efficient energy use not only supports sustainable production but also aligns with broader environmental goals, ensuring the long-term viability of the plantation sector in India.

Alternative energy resources were first given a serious thought at a global level during the oil shock of years 1973–1975. In the subsequent years, efforts were made to develop feasible technologies to use renewable resources like air, water, solar energy, etc. The global concern for degrading environment and the growing energy crisis in the recent decades has rejuvenated interest in alternative energy resources. Biomass energy is one of the most promising new alternatives that have attracted attention of scientists and researchers looking for cleaner sources of energy.

Technically biomass is defined as '*the total mass of all the organisms of a given type and/or in a given area.'* It is expressed in terms of grams of dry mass per square meter. Bio energy thus includes energy from all plant matter and animal dung that can be converted into useable forms of energy like fuels, electricity, etc. One distinct advantage of biomass over other renewable resources is that it can

be made available almost anywhere. It offers opportunity for sustainable, self-reliant and equitable development of energy resources all over the world.

Biomass energy has several applications in different planation crops. Some of them are listed below:

- Tea processing is energy-intensive, requiring significant heat for withering, drying and processing. Traditionally, this energy is supplied by burning firewood or fossil fuels. However, some tea estates have begun using biomass residues, such as pruned tea bushes and other organic waste, to generate heat.
- Coffee processing involves drying coffee cherries and beans, which also requires substantial energy. Coffee husks and other by-products are increasingly being used as biomass feedstock in some plantations.
- Spices like cardamom, pepper and vanilla require drying, which can be energy-intensive. Biomass from pruning and other agricultural residues is being explored as an alternative to conventional fuels.

Following are the techniques that can be used to generate useful forms of energy from biomass:

- *Combustion:* Biomass combustion provides the basic energy requirement for cooking and heating of rural households. It is also used in a variety of traditional industries in developing countries. Potentially biomass can provide a much more extensive service than it does now by means of efficient design improvements.

  For example, the smokeless C*hula* and the biogas plants at rural levels have provided a cleaner and more efficient method of cooking in many villages. An industrial biomass combustion system normally consists of fuel storage, feeding device, the combustor, ash removal device, heat recovery surface, flue gas cleaning facility and stack. For efficient use, it is important that the combustor design be according to the biomass fuel used. Described below are some of the processes used in biomass energy production.
- *Gasification:* Gasification is the process of converting a solid fuel into a combustible gas by supplying a fixed amount of air/oxygen. The figure below shows a schematic diagram of a gasifier configuration. The producer gas thus produces can fuel furnaces and engines.
- *Densification:* Using agricultural and forestry residues is often difficult because of their unevenness and storage problems. A process called densification can overcome this drawback. In this process, the residues are compacted into a product of higher bulk density and a regular shape. It is basically a hot compaction process in which the lignin component of the residue softens and acts as an internal glue to bind the mass together.

  Depending on the type of equipment used, densification can be classified into four main categories: piston press densification, screw press densification, roll-press densification and pelletising. Products from the first three types of densification are bigger in size and are commonly known as *briquettes*. Following are the important advantages of densification:

  - Increase in net calorific value of the raw material.
  - The end product is easy to transport and store.
  - The fuel produced is uniform in size and quality.
  - The problem of residual disposal is taken care of.
  - The process reduces deforestation.
- *Biomass Carbonisation:* Carbonisation is the process in which biomass is heated in the absence of oxygen and is thus converted into a low volatile fuel called charcoal. Charcoal derived from wood is widely used in developing countries for cooking and has wide applications in industries. But using wood charcoal causes deforestation and it is often difficult to find adequate supply of firewood for this purpose. Substitution of wood by bio coal that is briquette-charcoal obtained from agricultural and a forestry residue is thus an attractive alternative for rural energy demands.

In recent years, *torrefaction* or roasting of biomass has gained popularity in some European nations. In this process the biomass is subjected to a temperature of about 250 degree Celsius, resulting in a product that has 80-90% of energy retention and is hydrophobic in nature.

GASIFICATION OF WOODY BIOMASS FOR EFFICIENT ENERGY APPLICATIONS

Gasification is defined as a thermo-chemical process in which fuel gas is formed due to partial combustion of biomass. The plantation industry provides waste biomass in various forms, which can be used for meeting the energy requirements of the industry. Gasification is a clean and efficient and clean mode of generating energy from biomass for thermal, mechanical or electrical applications. Introduction of gasification technology in plantations seem beneficial because of the following reasons:

- It enables better scope for efficient utilisation of biomass.
- Equipment for gasification is more compact compared to existing devices for biomass combustion.
- It can provide both process heat and electricity for the estate operations.

The following are some field observations that describe present energy consumption and scope for induction of gasifiers systems in coffee plantations:

Curing of parchment and cherry coffee produces 20% and 50% husk respectively. Parchment husk cannot be briquetted as such because it has no lignin, but cherry husk can be gasified either directly or in the briquette form. Since large quantities of husk are readily available at curing works, gasification can help in meeting the electrical and process heat requirements (for drying) of the curing process. Generally, kerosene or high-speed diesel is used as fuel for coffee roasting. Producer gas burners of appropriate design can replace the kerosene or high-speed diesel burners. Calculations prove that gasifier-based coffee roasting systems can bring down the cost of fuel to one third of the present value even after inclusion of electricity cost for blower operation and interest cost for gasifier set up. The exit temperature of gas at the grate is about 1000-1150K depending on the flow rate. Producer gas thus produced is combustible and can be used for firing furnaces (Palaniappan, Kumar & Haridasan, 1993).

As explained by Ravindranath and Hall in their study (1995), the technology of gasification can have tremendous impact on energy generation in India considering the fact that the total potential of gasification energy, including agricultural wastes is estimated to be about 10000–15000 MW. It is imperative that this potential should be tapped in every possible manner. But in plantations, like in many industries, the cost of value addition by opting for bio energy is less than 10%.

Thus, if grid electricity is available, people tend to use it indiscriminately because it is cheaper. It is thus important to educate them about energy conservation and better utilisation of resources.

Energy Plantations as a Solution to Energy Crisis

Dry fuel wood has a calorific value in the range of 3500kcal/kg-5000kcal/kg, close to that of coal that has calorific value of about 4200kcal/kg. But fuel wood is a much cleaner source of energy and is also relatively renewable in nature. Thus, using fuel wood instead of coal can be a potential alternative to the rural energy crisis. Calculations show that for 1MW of generating capacity about 1 sq. km area of fuel wood area is required. This is based on the biomass output that can be sustainably obtained from a captive energy plantation.

Much of the success of generating biomass-based power generation will depend on what yield levels can be achieved in these areas, which in turn depends on the agro-climatic conditions of the region. The common species that can be grown into energy plantations are *Eucalyptus* sp., *Acacia auriculiformis* and *Casuarina equisetifolia.*

The commonest of these is the Eucalyptus sp. But now scientists are studying the potential of Casuarina tree as well. This is a fast-growing species and loses much less water by transpiration as compared to the Eucalyptus, while giving almost same calorific value. Given below is a table that gives details about the calorific values of these species:

Table 1

Name of Species	*Calorific Value in kcal/kg*
Casuarina equisetifolia	4950
Eucaluptus grandis	4900
Eucaluptus tereticornis	4800

Source: Adapted from 'Energy Perspectives in Plantation Industry' by Palaniappan, Kumar and Haridasan (1993).

The output of biomass from a given area is related to the spacing between plants. The spacing should be such that we get optimal growth of the plants as well as increased yield per unit area. The appropriate spacing for Casuarina is 1m x 1m with a hexagonal planting pattern. Harvesting should be done at the end of the exponential growth phase; in this case it is between the fourth and the fifth year. At the end of five years each Casuarina can be expected to yield about 20 kg of biomass.

We can calculate the yield per hectare per year as follows:

(No. of trees per hectare x No. of Kg of biomass yield per tree x Dry mass fraction) / No. of years

i.e. (1150 x 20 x 64) / 5 = 2944 Kg

Thus about 30 tons of biomass per year can be generated, which is a significant contribution to clean energy production.

Another advantage of growing Casuarina plantation is that it needs labour for proper growth and maintenance, and hence can generate employment. In fact, every MW power generates about 56000 hours of man days. An advanced method for raising large number of plants for afforestation is micro propagation or tissue culture technique. Eucalyptus species is also a fast growing and short duration fuel crop. It is one of the cheapest sources of fuel for tea plantation, and is also useful in article manufacture. Conventional methods of vegetative propagation to produce uniform plants have not yielded good results for *Eucalyptus grandis* and so the tissue culture method was adopted as early as in 1985.

Since then continuous research has finally led to successful standardisation of this technology to a commercial level with high rate of multiplication and high survival rate in the nursery. The success substantiates the potential of this tissue culture technique for improving the productivity of fuel wood plantations. Thus, energy plantations have tremendous potential of developing into a powerful energy resource, especially in the rural areas. But this area still needs a lot of research and efforts from government as well as NGOs for reaching that status.

Environmental Impact and Other Limitations

This article has highlighted the numerous benefits of using biomass as an alternative energy resource. But it is also true that there can be profound impact on the environment due to large-scale combustion of biomass. Scientists are currently studying the overall impact of introducing this alternative on a commercial scale and some of the negative effects are given below:

- *Large Scale Deforestation and/or Degradation of Forest Resources*

Since biomass energy deals mainly with utilisation of fuel wood it is feared that it may cause depletion of already thin forest cover in the country. Hence, it is imperative that the concerned authorities take up compensatory replanting of trees, even if they are meant for energy purposes only, seriously.

- *Loss of Biodiversity and Land Degradation*

Energy plantations on a commercial scale may threaten the biodiversity of plants as more and more attention will be given to only the trees. This may in turn affect the animals that are dependent on these trees for nutrition and habitat. It may ruin the food chain and environmental balance of the area in the long run. Another serious impact of energy plantation can be in the form of lands degradation. Many of the energy crops do not enhance the soil quality: some even damage it by altering its texture and pH conditions. They also do not offer protection from topsoil erosion.

- *Domestic Air Pollution from Combustion*

One of the major applications of biomass-generated energy is in rural areas for cooking and heating purposes. Combustion of biomass fuels can cause a lot of air pollution if the design of the application equipment is not proper. For example, the traditional *Chula* used in kitchens in Indian villages gives a lot of smoke that harms the health of the women and children in vicinity. It is thus essential that people be educated about efficient techniques of

using this energy resource, and that improved designs are made easily accessible even in remote areas.

Besides these, the following challenges can be visualised in implementation of this technology:

- *High Initial Investment:* Setting up biomass energy systems can require significant initial investment. This includes costs for biomass boilers, gasifiers and infrastructure for handling and processing biomass.
- *Supply Chain Management:* Effective collection, transportation and storage of biomass feedstock are critical. Variability in biomass availability can affect the reliability of energy supply.
- *Technology and Expertise:* Adoption of biomass energy requires access to appropriate technology and expertise. Small-scale farmers and plantations may lack the necessary knowledge and resources to implement biomass energy systems efficiently.

Bearing in mind the tremendous potential that biomass energy has and all the above-mentioned possible problems it might trigger we can conclude that right now we are sitting on a gold mine that can be ours if we act sensibly.

Each of the above-mentioned environmental hazards could be taken care of by taking timely action. Replanting, creating and spreading awareness and better designing of energy equipment can answer most of the environmental concerns. After all, the very purpose of introducing biomass as a substitute to fossil fuels is to create a safe and sustainable environment for mankind.

CONCLUSION AND RECOMMENDATIONS

Biomass in form of cultivation and processing residues can play an important role in meeting energy requirements of the plantation industry and even beyond it. For example, drying is a common requirement in most of the plantation processing techniques. Usually hot air produced by steam coils is used for this purpose. Burning of residues can be considered as a substitute to this provided energy conservation practices are followed. Since biomass contains little or no sulphur, the flue gas can be cooled at temperature below the dew point without the danger of corrosion. Hot air for drying can also be produced by heat exchange with fuel gas produced from biomass combustion.

Another critical requirement of the plantation industry is electricity for operating the various processing equipment. Use of residues for cogeneration of heat and electricity is an established practice in several agro industries. This can also be applied to the plantation industry, by setting up a gasifier-steam injected gas turbine cogeneration system. Bio coal production from plantation residues is also an attractive energy option, like production of briquette charcoal from coffee husk.

The biomass gasifier system has potential for application in plantation crops other than coffee also. It can be used for cardamom curing, energy generation from coffee shell, gasification of wood in tea plantations, replacement of furnace oil with tobacco waste in the cigarette industry and so on. This technology can be truly beneficial only when a concerted and integrated R&D program involving research institutes, manufacturers, funding agencies and users is implemented.

Based on the above facts and analysis the following courses of action are recommended:

- *Encourage Pilot Projects:* Implement pilot projects in key plantation areas to demonstrate the feasibility and benefits of biomass energy.
- *Financial Incentives:* Provide subsidies, grants and low-interest loans to support the initial investment in biomass energy systems.
- *Technical Assistance:* Offer training and technical support to farmers and plantation owners to build capacity and expertise in biomass energy technologies.
- *Develop Supply Chains:* Establish efficient biomass supply chains to ensure reliable feedstock availability. This can include community-level biomass collection and processing centres.
- *Policy Measures:* Strengthen government policies and regulations to promote biomass energy adoption. This can include tax incentives, feed-in tariffs for biomass-generated power and support for research and development.

The policy landscape in India is increasingly supportive of biofuels and biomass energy, particularly in the plantation sector. Central and State Governments have introduced various policies and financial support mechanisms to encourage the use of biomass residues for energy production. These initiatives aim to reduce reliance on fossil fuels, promote sustainable agricultural practices and enhance energy security in the plantation sector. By leveraging these policies and financial supports, plantation owners can adopt biofuel technologies, contributing to a more sustainable and resilient agricultural industry

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