FEASIBILITY OF SMALL SCALE BIOMASS POWER PLANTS IN SRI LANKA

PREPARED BY

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PREPARED FOR

BIOMASS ENERGY PROJECT 2022
SRI LANKA SUSTAINABLE ENERGY AUTHORITY

Ministry of Power

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UNDP

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Executive Summary

Sri Lankan Government has taken many decisions to establish mini scale (below 10MW) biomass (Dendro) power plants during last 36 years but the establishments are progressing very slowly. The first report of this initiative on "Fuelwood plantation study" has been published on September 1994 by the Energy Conservation Fund. With a decision given by the Cabinet of Ministers on 18th August 2004, an Inter-Ministerial Working Committee (IMWC) was appointed by the Hon. Minister of Power & Energy with a view to prepare an action plan to develop biomass powered electricity generation industry to a much larger scale. Under this five year action plan, considering policy, economic, technical and social benefits, establishment of 100 MW was proposed in three phases by 2010. Also, the committee has proposed special tariff with 8.50 LKR/kWh for first seven years and 7.00 LKR/kWh for remaining 8 years (this is for 15 year contract).

After establishing the Sri Lanka Sustainable Energy Authority in 2007, a separate tariff has been announced for dendro power plant and the last tariff was published in January 2012 and it was an escalable tariff with the economic conditions of the country and was proposed as 23.44 LKR/kWh for the first year and 29.36 LKR/kWh for the 20th year.

However, the dendro power plants have not been established as expected in the ground level. The total capacity available in the country now is 38.7MW and out of these only 60% of the capacity is successfully operating.

It has been noticed that the supply of the biomass at correct time is the major issue in establishing power plants. With this background, it has been decided to scale down the capacity of a power plants and study the most suitable solution.

Considering all the above, this study presents the feasibility of small-scale biomass power plants by identifying appropriate technology, evaluating financial feasibility and establishes aspects of the supply chain for the plant for smooth operation. This analysis has been done selecting a specific location for establishment of small scale biomass power plant in Ratnapura district and the main findings of the study are given below.

- Steam turbine and improved Gasifier technologies are technically and financially feasible for power plants from 0.5 MW to 3MW
- The IRR for these technologies range from 22 to 31% over the lifetime of 20 years
- The sensitivity analysis reveals that IRR of the project is very sensitive to the cost of biomass. So controlling the cost of biomass is crucial for financial feasibility of the project.
- The cost of biomass should be between Rs.3.50 and Rs.4.20 in order to keep the IRR above 20 %
- Analysis of the supply chain reveals that the most economical radius of collection from the power plant is 25 km from the power plant and 1.5 km from the main roads
- In order for the supply chain to access even small quantities from remote areas, a middleman modality is recommended. In this modality the middleman collects fuelwood from remote areas to control transports costs so that even small quantities can be accessed
- By designing the power plant to operate on a mix of agricultural waste and fuelwood, the project can be made more resilient to price and supply of fuelwood

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CHAPTER 1: IDENTIFICATION OF TECHNOLOGIES AND CAPACITIES AVAILABLE IN THE MARKET FOR SMALL SCALE BIOMASS POWER PLANTS

1. Available Technologies

It was determined that the chosen technology would have to be practical and successfully utilized in other similar situations in order to provide a reasonable assurance of commercial viability. Technologies that are currently on the cutting edge of technology for similar situations were reviewed and eliminated. The selected biomass project would have to have a reasonable chance of economic success in order to justify the investment.

Two primary techniques are utilized in the conversion of biomass fuel to power. These are:

- Direct Combustion
- Pyrolysis/Gasification

Gasification based power generation systems are being practiced during last 20 years in Sri Lanka but most of them had failed mainly due to technological issues. Most of these technologies didn't have proper solutions for controlling tar or cleaning the tar before supplying to the gas engine. However, this report presents a modern improved gasification technology developed by Korean scientists and it is in operation successfully with different types of biomass in many parts in the world.

1.1. <u>Direct combustion based power generation</u>

Combustion is a process in which the fuel is burnt with the oxygen from the air to release the stored chemical energy as heat in burners, boilers, internal combustion engines and turbines. The scale of combustion devices encompasses a few amount of thermal input such as a single gas ring for cooking, to huge coal fired combustion boilers with inputs of 3 - 5 GW in a single unit serving the electrical needs of almost 1 to 2 million households.

In the case of biomass the combustion process releases carbon dioxide, which was removed from the atmosphere by photosynthesis, and thus maintains an equilibrium level of carbon dioxide, unlike the combustion of fossil fuels which increase the level of carbon dioxide by releasing the carbon that was long ago stored in the earth. Carbon dioxide is the leading greenhouse gas and the use of biomass is as a result neutral with respect to global warming potential. There are however, a number of environmental costs of biomass combustion, which require innovation and significant investment for their mitigation. These costs include both direct human health impacts as well as environmental damage to the earth's productive ecosystems.

1.1.1. Basic component of the plant

The state-of-the-art Power Plant will consist of a biomass fueled steam boiler capable of generating high pressure and temperature steam. Based on the power plant capacity, condensing steam turbine and generator, a cooling tower, a biomass fuel preparation, storage and reclamation system, an ash handling system, an electrical distribution/switch system, and a boiler are the main components of the power generating system. Electrostatic precipitator, mechanical cyclone dust collector, water scrubber, low NOx burners if and as required to control combustion air to minimize the emissions of nitrogen oxides (NOx) and carbon monoxides (CO) are considered emission control techniques. Superheated high-pressure steam generated from a biomass fueled boiler is expanded in a condensing steam turbine-generator to produce electrical energy. A water-cooled condenser will be equipped with the condensing turbine to maximize the negative condensing pressure. The cooling water to the surface condenser will be in a closed loop and heat from the condenser will be ejected in the cooling tower inside the closed loop.

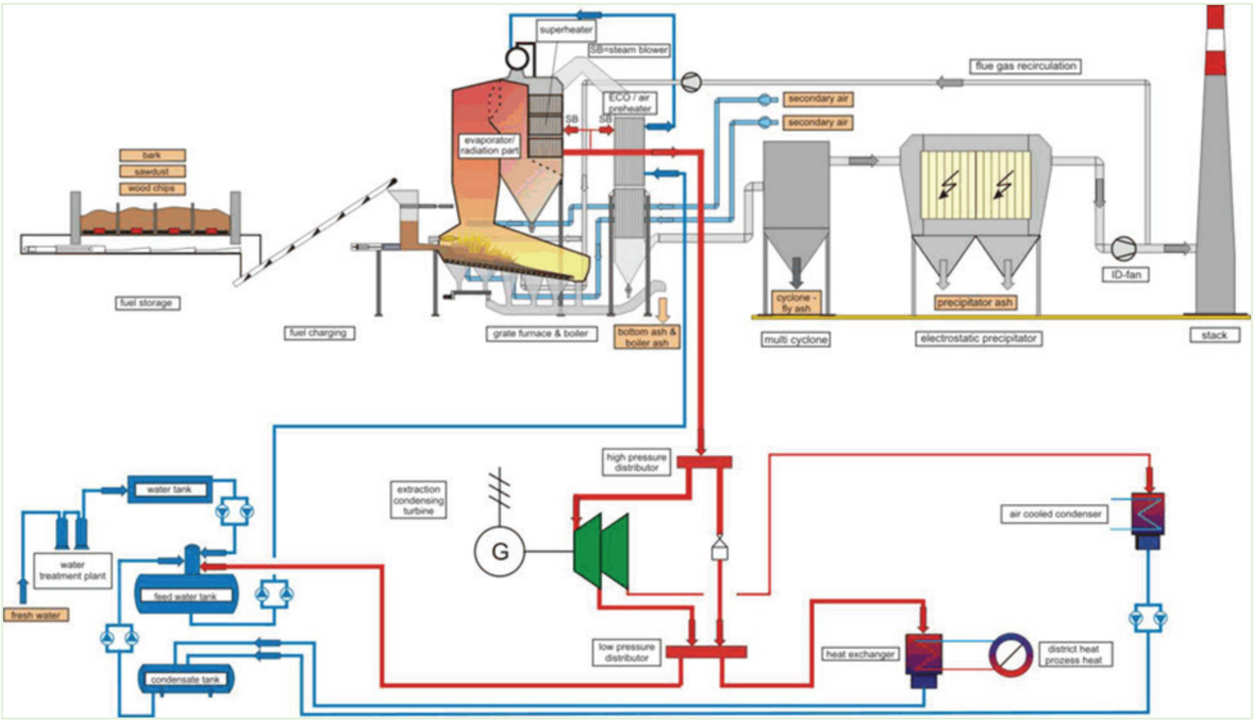
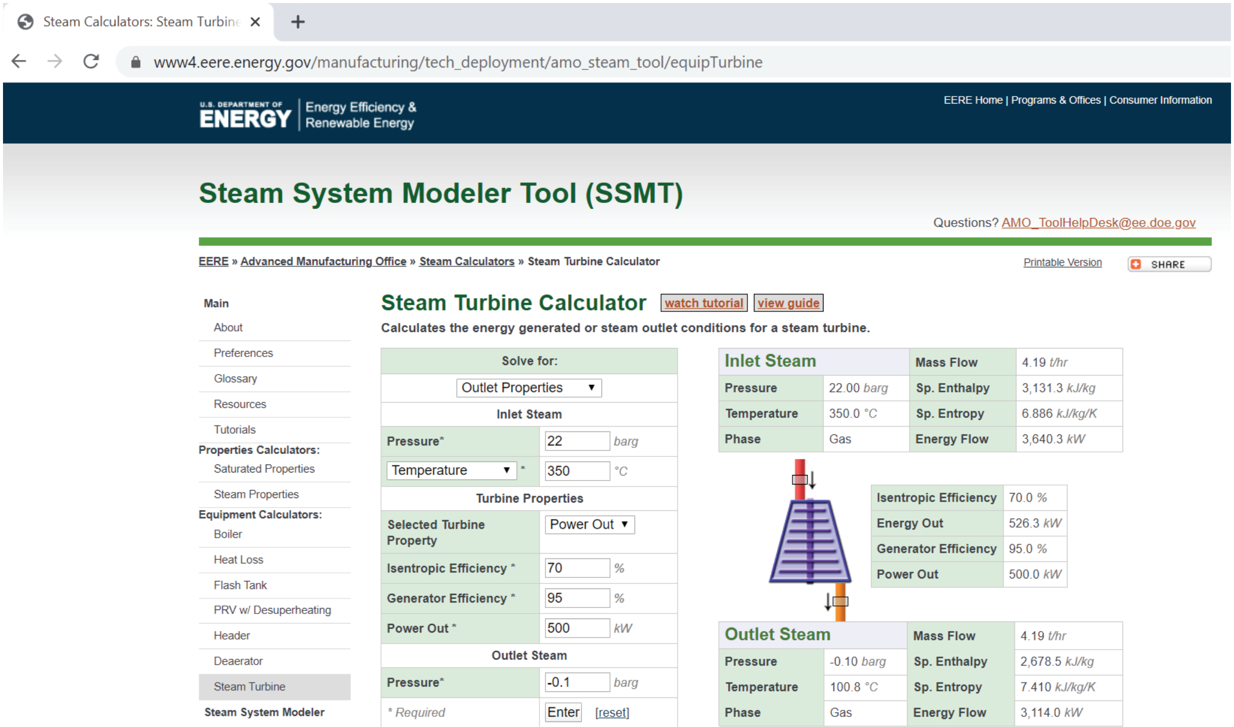


Figure 1.1: Schematic diagram of steam turbine based electricity generation system.

The Power Plant cooling system will consist of a steam surface condenser connected to the steam turbine condenser, cooling tower, circulating water pumps, and auxiliary cooling system pumps. The cooling water will be pumped out of the cooling tower basin by the circulating water pumps, through the condenser and back to the cooling tower. Cooling water for the generator air coolers, lube oil coolers and other auxiliary equipment will be pumped from the circulating water line through the equipment and returned to the circulating water line by the auxiliary cooling system pumps.

1.1.2. Operating efficiency

The performance of a steam turbine based power generation system has been evaluated using following software published by U S Department of energy which is freely available on the internet. The following specimen calculation is done for 500 kW power plant with 65% isentropic efficiency of the turbine system.



Approximately 8.3 kg of superheated steam at 22 barg and 350 ^{0}C with exhaust pressure of -0.1 barg is required to generate one unit of electricity and in terms of firewood with 35% moisture the specific ratio is 2.5 kg of firewood/kWh. The specific details of operation are given in the following table for different capacities.

Table 1.1: Variation of the steam flow with different capacities of steam turbines

Capacity - kW	Steam pressure - barg	Steam temperature ^{0}C	Steam mass flow – t/hr	Isentropic efficiency-%	Generator efficiency - %	Steam outlet pressure - barg
500	22	350	4.19	70	95	-0.1
100	22	350	8.37	70	95	-0.1
1500	40	375	11.86	64	95	-0.1
2000	40	375	15.81	64	95	-0.1
3000	40	375	23.71	64	95	-0.1

A specification sheet developed by Qingdao Energy Engineering Co., Ltd. Rm 1506, BLDG 3, 178-2 Haier Road, Qingdao, 266061, China for 500 kW steam turbine based power generation system is attached in annex i.

1.1.3. Level of automation

- Fuel in Feed System

Small pieces of biomass are recommended for the combustion. Processed fuel wood needs to be loaded in to the feeding hopper manually and then the fuel moves via conveyors in an environmentally acceptable and controlled manner into the screw feeder. Supply of fuel is regulated automatically or manually with respect to the boiler requirement.

- Combustion System

The fuel, which is conveyed, is discharged into a bin complete with screw feeders that regulate the amount of fuel into the boiler combustor automatically.
All of the combustion controls required to provide operator interface both locally and remotely to monitor and efficiently control the combustion of the wood residue via a boiler control master will be included.

- Steam Generation System

The hot combustion gases will enter into the steam generator (boiler). The steam boiler needs to be supplied in accordance with the American Society of Mechanical Engineers (ASME) Boiler and Pressure Vessel Code – Section 1. After exiting the boiler, the hot gases enter in to an economizer which further extract thermal energy from the gas stream and transfers its heat into the feed water. The gases then enter a flue gas system.

- Electrical Generation System

The superheated steam from the boiler is connected to a condensing steam turbine-generator. The steam is allowed to expand through the turbine and exhaust into a surface condenser to a negative pressure to convert the mechanical energy into electricity. The condenser is a surface condenser and cooling of the surface condenser is by cooling water which is interconnected with a cooling tower. The generator will automatically synchronize with the utility bus. The functions and data required for operation and monitoring the turbine generator is interconnected with the main plant control system.

1.1.4. Suitable feedstock

- Composition of feedstock

Depending on the configuration of the combustion chamber, the type and the size of fuel used is varying. There are three major configurations and most commonly, grate stokers are used in small power plants. The characteristics of the suitable feedstock is described below.

- Moisture content

Moisture content of the fuel needs to be maintained in the range of 25% to 40%. It has been observed that the moisture content of some of the fresh biomass such as Gliricedia is around 55% to 60%. It is strongly recommended to feed dry material with 25% to 30% moisture content as much as possible so that the boiler overall efficiency will be increased.

It is recommended to store chipped biomass in a closed warehouse for at least one week's time so that the moisture content reduces up to around 25% to 30%. In emergency conditions wet biomass can be mixed with dry material such as paddy husk and the moisture content can be adjusted as suitable to the combustion chamber specifications.

Different Combustion Mechanisms Available in Steam Boilers

- Underfeed Stokers

Biomass is fed into the combustion zone from underneath a firing grate. These stoker designs are only suitable for small scale systems up to a nominal boiler capacity of 6 MWth and for biomass fuels with low ash content, such as wood chips and sawdust. High ash content fuels such as bark, straw and cereals need more efficient ash removal systems.

- Grate Stokers

The most common type of biomass boiler is based on a grate to support a bed of fuel and to mix a controlled amount of combustion air, which often enters from beneath the grate. Biomass fuel is added at one end of the grate and is burned in a fuel bed which moves progressively down the grate, either via gravity or with mechanical assistance, to an ash removal system at the other end. In more sophisticated designs this allows the overall combustion process to be separated into its three main activities:

Initial fuel drying
Ignition and combustion of volatile constituents
Burning out of the char.

Grate stokers are well proven and reliable and can tolerate wide variations in fuel quality (i.e. variations in moisture content and particle size) as well as fuels with high ash content. They are also controllable and efficient.

- Fluidized Bed Combustion

The basis for a fluidized bed combustion system is a bed of an inert mineral such as sand or limestone through which air is blown from below. The air is pumped through the bed in sufficient volume and at a high enough pressure to entrain the small particles of the bed material so that they behave much like a fluid. Light material such as paddy husk, bagasse, sawdust etc. is more suitable for this type of burners.
The combustion chamber of a fluidized bed plant is shaped so that above a certain height the air velocity drops below that of necessary to entrain the particles. This helps retain the bulk of the entrained bed material towards the bottom of the chamber. Once the bed becomes hot, combustible material introduced into it will burn, generating heat as in a more conventional furnace.
Bubbling fluidized bed (BFB) combustors are of interest for plants with a nominal boiler capacity greater than 10 MWth. Circulating fluidized bed (CFB) combustors are more suitable for plants larger than 30 MWth. The minimum plant size below which CFB and BFB technologies are not economically competitive is considered to be around 5-10 MWe.

- Ultimate analysis

The ultimate analysis is useful in calculating the quantity of oxygen (and thus combustion air) required to sustain the combustion reactions. It also permits the estimation of the amount of water formed by burning hydrogen in the fuel. During the combustion heat is absorbed to vaporize and exhaust this moisture in addition to the inherent fuel moisture. Recommended values of ultimate analysis of the suitable fuel are given bellow.

Carbon	38% to 51.0%
Hydrogen	5.0% to 6.0%
Nitrogen	0.3% to 0.8%
Oxygen	35.0% 42.7%
Sulphur	<0.05%
Ash	2.0% to 19.0%

- Energy content/Heating value

Energy content of the 100% dry fuel would be 18.5 MJ/kg and this value is varying with the moisture content. For an example the heating value of biomass having 30% moisture would be around 13.0 MJ/kg.

- Size of the fuel

The maximum size of the fuel particle would be 4”. The feeding of biomass needs to be controlled automatically or partially automatically with respect to the output parameters of the power plant. Therefore the quality of feeding material should be uniform in physically and chemically.

1.1.5. Natural resources required

Other than the fuel, water is the only natural resource required to run these systems. In steam based power plants, water is required for boiler, cooling tower and lube oil cooling system. Approximately 2.5 m^3/hr of fresh water is needed to operate a 1MW power generating system to fill the evaporation losses. Steam and water flow between boiler and the turbine are operating as a closed loop system and evaporation losses are taken place at the cooling tower.

1.2. <u>Pyrolysis/Gasification based power generation</u>

Gasification is the process of converting biomass/coal into a combustible gas. Any carbon-containing material can be converted into a gas composed primarily of carbon monoxide and hydrogen. This gas can then be utilized as a source of fuel such as may be used to drive a combined cycle gas turbine.

The gasification process controls the temperature and pressure to convert biomass into low or medium BTU gas in a reducing, or oxygen starved, environment. Gasification has been used for almost two hundred years. Early gasification development utilized coal as the source of fuel to make a gas referred to as town gas. Today, there are many research and test projects using wood wastes, forest cuttings, and manufacturing wastes.

The process generally has two steps: pyrolysis and char conversion. The pyrolysis step releases volatile components from the fuel when it is heated in an environment where the air in the reaction is typically much less than that found in the firebox of a boiler. The temperature is generally maintained between 400 ˚C and 600 ˚C to release a complex gas called syngas, producer gas, wood gas, etc. Gasification appears to offer a promising future; as systems are developed and improved. A great deal of research has been conducted in the recent past to enhance the overall performance of the gasification based power generation systems, but overall cost to create power compared to contemporary power sources is still in higher range.

Gasification is the thermal decomposition of feedstock in the presence of sub- stoichiometric oxygen to produce combustible gas (syngas), which is rich in carbon monoxide and hydrogen. With an insufficient amount of oxygen, oxidation is limited and the thermodynamics and chemical equilibrium of the system shift reactions and vapor species are in a reduced rather than an oxidized state. Consequently the elements commonly found in fuels and other organic materials (C,H,O,N,S) end up in the gas stream as CO, H , CH , H O, CO, N2 and lesser amounts of H S, SO , HCI, elemental carbon and trace quantities of other hydrocarbons depending on the biomass waste input.

1.2.1. Basic component of the plant

- Gasifier reactor

The modern Gasifier systems use a modified moving bed gasifier which is designed to produce a combustible syngas from a variety of combustible solid materials which can be supplied to chemical synthesis processes or a boiler or used directly in an internal combustion gas engine or dual fueled engine to produce electricity and heat. Each gasifier system is mainly designed to process 1,000 to 1,250 kg per hour of biomass and or waste RDF and a range of other industrial and domestic waste products per gasifier module with the resulting syngas being converted into heat/electricity by a spark ignition or duel fuel compression standard engine generators. Alternatively the syngas produced from the gasifier can be utilized for the synthesis of chemicals.

The modern system is designed to be economically feasible at a modest scale and is capable of using a variety of low grade fuels and contributes not only to energy production but also to the achievement of renewable energy and biomass industrial waste management goals. The reactor vessel has the advantages of requiring no external energy supplies and of containing no moving parts in the high temperature areas of the process, which serves to the ambition of increasing the life and reliability of the system. The system consists of moving bed modified gasifier reactor and a gas clean- up train, which contains the dust cyclones, gas coolers, wet scrubber, high voltage plasma (HVP), demister filter, gas blower and flare stack. The whole system works under vacuum (negative pressure), which is developed by the gas suction blower at the required system pressures.

Figure 1.2: Gasifier and Syngas Engine

- Ash Discharge

Ash discharge from the gasifier bottom is affected by a single roller crusher provided for each reactor. The ash drops onto the enclosed ash conveying system, which is cooled by a water bath and is transported to the ash skids.

- Igniters

Single or twin igniters are fitted to the gasifier. The torch construction consists of a length of stainless steel tube to one end of which is screwed a stainless steel burner head. A high tension (HT) pulse coil is housed at the other end of the torch.

A conductor rod, supported by insulator assemblies, runs concentric with the bore of the tube. The rod is screwed into the HT Coil and terminated at the burner head with a heat resisting spark-flame electrode.

A low tension pulse is fed into the ignition coil via an approved four pin connector and the resultant HT spark is created across the gap between the spark electrode and the burner head. Either natural gas or propane may be used to ignite the feedstock in the gasifier.

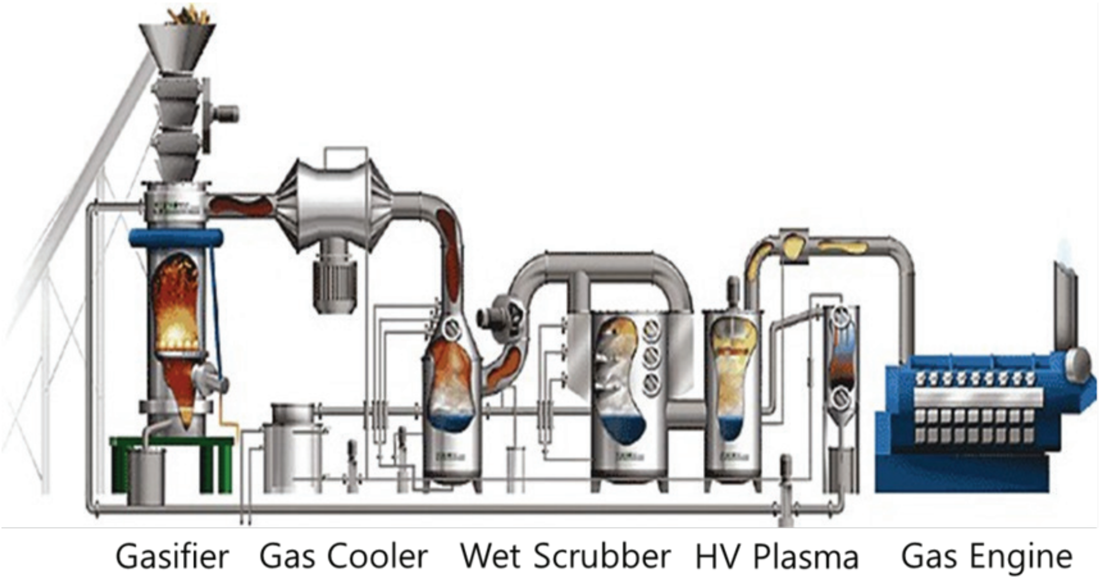


Figure 1.3: Schematic diagram of gasifier based electricity generation system.

- Dust Cyclones

A pair of identical hot gas coarse dust cyclones, designed to take 10 micron and above gas dust particles, is installed in the gas clean-up train where it exists from the gasifier. Their purpose is to collect fly ash, dust and particulates from the gas stream prior to further clean-up. The contaminants captured by the cyclones are delivered by augers to the ash collection hopper at the base of the gasifier to achieve continuous removal of impurities from the system.

- Gas Coolers

The product syngas temperature is reduced via shell and tube heat exchangers using ambient air and or water. Syngas enters the gas cooler around 600˚C and leaves around 100˚C. Waste heat collected in gas coolers is returned back to the gasifier to prevent heat loses.

- Water Scrubber

The syngas enters the wet scrubber where it is first saturated with water by the action of sprays in a venturi section. The cooled saturated gas then passes upwards through HVP where it is scrubbed by water fogging system.

From the venturi water scrubber the liquor gravitates via return pipe to the integral recycle tank at the base of the scrubber.

The scrubbing liquor is pumped to the humidifying sprays and to the HVP. Temperature of the syngas is reduced to 40˚C from 100˚C after the water scrubber. The scrubber condenses water from the gas stream resulting in a dilute effluent stream containing solids and acid components of the gas stream, which is blown down and this serves to control the level of particulates in the scrubbing liquor. A ball float valve maintains the water level within the scrubber.

- High Voltage Plasma (HVP) Cleaning

The modern gasifiers HVP equipment is located just after the venturi scrubber and is specifically designed for biomass waste gasification syngas cleanup. This system will be comprised of a vertical flow tubular HVP system. These units are of rigid frame design with fixed point suspension for the high voltage discharge electrode system and have been installed for collecting different types of particulate, soot, tars and aerosols.

The HVP embodies many unique design features that ensure high collecting efficiencies over an extended lifetime with a minimum of preventative maintenance.

The HVP uses a multi-stage action to collect fine particles and tar with mist. Prior to entering the collector tubes, the process gas will pass through a fogging quench system to cool and saturate the gases. As the gases enter the up flow ionizing stages, the particles and the mists are charged in a corona, generated by points extending from disks on the ionizing rods. The charged particles go to the collecting stage, where they are attracted to a collection plate (inside surfaces of tube walls). Subsequently, they are washed down the plate by a film of water or mists which is formed by the use of fogging nozzles upstream of the collector section or by the acid mists itself. These events are repeated many times in each tube, with each tube containing one ionizing rod.

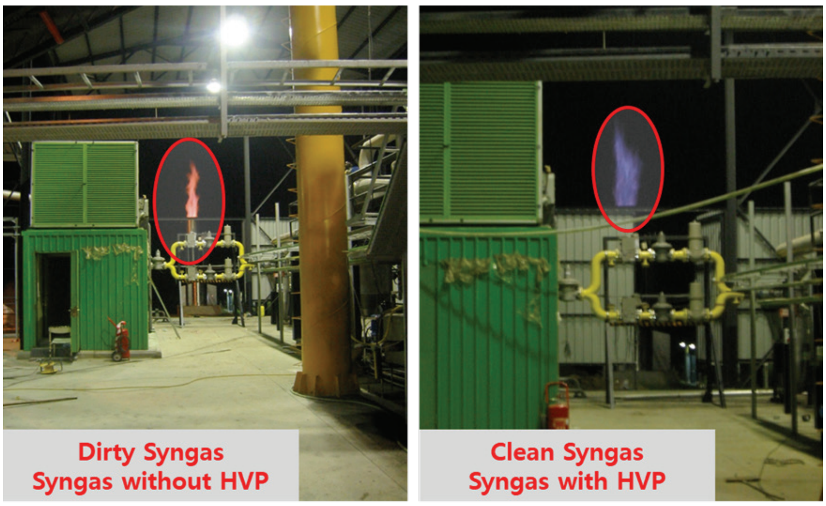


Figure 1.4: Gasifier and Produced Syngas at Flare

- Coalescent Cyclone Separator

After the gas cooler, there is a 300mm coalescent type cyclone separator that is installed for removal of the condensed water and remaining tars from the gas. The cyclone has an EN1092-2: 1997 PN16 RF flanged inlet, outlet and 1½" BSPT (F) tapped vertically downward drain connection. The collected liquids will drain back to wet scrubber tank for eventual treatment by the water treatment system.

- Gas Suction Blower

The Blower is a compact, rotary lobe type axial flow blower. The meshing of two screw type rotors synchronized by timing gears provide controlled compression of the air for maximum efficiency and pulsation free of discharge.

Compression is effected by the main (2 lobe) and gate (4 flute) rotors meshing within an enclosed housing. The timing gears maintain close rotor clearances. The rotors do not touch each other, the housing, or the bearing carriers. Although clearances are small, lubrication in the compression chamber is not required, ensuring oil - free gas delivery. The compression cycle begins as the rotors un-mesh at the inlet port. Gas is drawn into the rotor cavities, trapped and compressed by the reducing cavities as rotation continues. When proper compression is made, the cavities cross the discharge port, completing the cycle. The cycle occurs twice for each revolution of the main rotor. The housing is a one- piece casting with flanged inlet and discharge openings.

Two heavy-duty angular-contact ball bearings are used on each rotor shaft, at the discharge end, as fixed bearings to maintain rotor and clearance. A redial bearing is on each rotor shaft at the gear end as a floating bearing. All gears and bearings are oil splash lubricated.

- Gasifier and HVP Control Panel Suite

The gasifier control panel suite will comprise of stainless steel floor standing wardrobe style enclosures, suitably braced to form a composite unit, mounted upon 100mm plinth affording ingress protection to IP55, complete with standard double bit cam-lock door locks. The enclosures will be equipped as follows:

a. Incomer Section comprising of a 400A TP&N molded case circuit breaker, complete with:
    - Electronic protection unit;
    - Terminal protection shields;
    - Door interlocked pad-lockable handle;
    - 415V AC/110V AC 2000VA transformer, protection miniature circuit breakers on 415V AC primary and secondary 110V AC output distribution circuits and links
    - "Power On" LED indication lamp.

b. Motor Starter Sections comprising of suitably rated TP isolating device, each section complete with:
    - Terminal protection shields;
    - Door interlocked pad-lockable handle;
    - Variable speed motor starters

Each of the above includes a motor application circuit breaker auxiliary contact block AC3 duty block type contactor, auxiliary contact block Variable Speed Drive module, keypad and Profibus communication card module/ Wiring to the required field terminations is run neatly within cable containment trunking.

c. PLC Section comprising of suitably rated DP isolating device, complete with:
   - Terminal protection shields;
   - Direct mounted handle;
   - 110V AC/24V DC 10A power supply unit, protection miniature circuit breakers on 110V ac input and 24V dc output connections and links.
   - PNOZ X3 Category 4 safety relay
   - Twin RCD protected metal clad 240Vsocket outlet
   - Internal panel lighting
   - Ethernet5 port unmanaged Switch
   - HMI mounted on door
   - Siemens S& PLC equipment (or equal)

d. Reactor Area Is i/o panels in a Stainless Steel wall mounting wardrobe style enclosure measuring 760mm H x 760mm L x 300mm D affording ingress protection to IP66, complete with standard double bit cam-lock type door lock.

e. Gas Clean-up Area IS I/O panels are located in a stainless steel wall mounting wardrobe style enclosure measuring 760mmH x 760mm L x 300mm D, affording ingress protection to IP66, complete with standard double bit cam-lock type door lock.

- Syngas Flare Stack

The flare stack will be approximately 3000mm in height with the following characteristics:

a. A 5mm thick stainless steel stack, from approximately 9000mm above ground level. The stack is designed for easy removal / refit without disturbing the ceramic liner.
b. A galvanized flare-stack base section containing the stainless steel combustion system and airflow control louvers.
c. 150mm thick ceramic wool liner, rated to 1260°C. The liner is in modular form with a concealed stainless steel attachment system which is not exposed to the combustion process.
d. Syngas ignition and pilot assembly with UV flame detection and automatic ignition and flame failure control.
e. 4x5" flanged particulate stack sample ports
f. Operating range for a typical syngas: 20 % to 100% of max. Flow.
g. Combustion temperature: >1000°C operating range.

1.2.2.Operating efficiency

The overall operating efficiency of gasifier based electricity generation system is considerably higher than that of the steam turbine based power generation system. The specific biomass use is 1.5 kg/kWh at 30% moisture.

- Clean Syngas Production

The low level of tars and particulates in the final product syngas is crucial for the reliable operation of the upstream gas separation process.

The seven stage gas clean up system includes cyclones for particulate control, gas coolers and air pre-heaters, a high efficiency water scrubber to cool the product gas and high voltage plasma (HVP) to control the fine sub-micron particulates in the syngas stream. The typical expected syngas composition from biomass gasification is given in the following table.

Table 1.2: Characteristics of syngas

Syngas	% Volume (Dry)
H_2	17.5
CO	20.8
CH_4	3.3
N_2	45.8
CO_2	11.4
C_2H_4	0.7
C_3H_6	0.4
GCV (MJ/Nm^3)	5.83

1.2.3. Level of automation

The system is operating with a flexible system which is integrated using advanced electronic controls, for optimum efficiency under diverse operating conditions.

1.2.4. Type of Biomass / Wastes can be used with modern gasification system

The modern technology is applicable to a wide range of biomass waste material, including:

- Woodchips and woody biomass materials
- Agricultural biomass such as coconut shells, palm shells etc.
- Combustibles recovered from Municipal and industrial wastes (RDF)
- Dry sewage sludge of wastewater treatment plants
- Rubber and plastics waste including tire waste
- Chemical and oily waste
- Other combustible none-hazardous solid materials (SRF)

1.2.5. Natural resources required

There is no substantial amount of natural resource requirement in this process other than the biomass.

1.3 Emission control

1.3.1 National standard

The Government has published extraordinary gazette No. 2126/36 on Wednesday June 05, 2019 containing regulations made by the President under Section 32 of the National Environmental Act, No. 47 of 1980, read with Sections 23J, 23K and 23L of that Act and Section 51 of the Nineteenth Amendment to the Constitution of the Democratic Socialist Republic of Sri Lanka.
These Regulations are cited as the National Environmental (Stationary Sources Emission Control) Regulations, No. 01 of 2019 and indicate the emission level that are needed to be maintained in stationary sources.

1.3.2 Emission control technique in steam boiler

- Flue Gas System

The cooled flue gases discharged from the economizer will enter a mechanical dust collector where the coarse ash particulates are removed from the gas stream and collected within a hopper. The flue gases will then be pulled by an induced draft fan into wet scrubber. A continuous emission monitor (CEM) will be provided at the stack outlet to monitor the flue gas exit conditions on a continuous basis.

- Ash Disposal System

The ash from the combustion of the wood residue fuel will come from three locations throughout the plant:

- The combustion chamber (coarse ash),
- The boiler and economizer hopper (fine ash), and
- The flue gas emission control system, mechanical (multiclone) dust collector hoppers and the wet scrubber (fine ash).

The coarse ash may be handled separately from the fine ash to a bunker with front end loaders used for removal of the coarse ash and the two sources of fine ash may be connected together within one final transfer conveyor which conveys the ash into a standard dumpster for removal by truck. Final disposition of the ash has not been determined, but it is likely to be a local municipal or commercial landfill authorized to handle such materials or return to land owners as fertilizers.

1.3.3 Emission control technique in gasifies

The modern Gasification Technology for biomass waste disposal and energy generation with production of syngas for electricity and heat fulfills the requirements of integrated prevention and reduction of environmental pollution, in comparison to existing incineration plants.
This is an entirely novel aspect. Thus common problems such as land filling of toxic residues and resultant unpleasant odor for residents do not occur. Moreover, the process works with slight low negative pressure, thus prevents the gas leakage and spreading of unpleasant odor even during the plant operation. The process releases back to the environment a far lower amount of harmful substances than permitted.

CHAPTER 2: FEASIBILITY OF THE IDENTIFIED TECHNOLOGIES FOR SMALL SCALE BIOMASS POWER PLANTS

2. Introduction

In this section, feasibility of technology for establishment of small scale power plant has been assessed. Financial analysis for each technology and SWOT analysis for factors effecting in implementation of technologies have been done and the results are given.

2.1 Economic and financial analysis of the technologies

In this study, techno-economic analysis has been conducted for each technology, steam turbine based power plant and for biomass gasification power plant. The analysis is built based on existing tariff structure published by the Ceylon Electricity Board and the actual prices of equipment obtained from the manufacturer. Land cost, construction, operation and maintenance costs, employees and structure costs, and grid interconnection cost have been estimated based on the market rate available in Sri Lanka. Cost of biomass has been estimated based on the details taken from the existing biomass power plant in Sri Lanka. A spreadsheet economic model combining net present value (NPV), internal rate of return (IRR) and payback period (PBP) is developed over the plant's lifetime period of 20 years. Revenues are generated from selling electricity to the grid. A sensitivity analysis is employed to gauge the economic model performance and investment risk.

2.1.1 Data and information for economic analysis

- Prevailing tariff

The present tariff structure has come in to operation from 1st January 2012 onwards and it has not been changed up to now. The available tariff is given below. As per the amendment done to the electricity act in 2013, there is no standard tariff for purchasing electricity and the tariff is decided through a competitive bidding process. More details are given in the chapter 4. Anyhow, as a ceiling, the tariff announced in 1st January 2012 has been taken for this analysis. Considering the economic changes occurred between 2012 and 2020, it is assumed there will be a tariff increase for biomass based power generation.

Table 2.1: Feed in tariff published in 1st January 2012

Tariff – Rs./kWh	
1-8 years	
Non-escalable	9.67
Escalable base O&M rate- 5.16%	1.52
Escalable base fuel rate - 3.44%	12.25
9 - 15 years	
Non-escalble	3.72
16 - 20 years	
Non-escalable	2.11

- Cost of biomass

Cost of fuel is the very sensitive figure in this analysis. Growing, cutting and transport cost is included when estimating the cost of biomass. The power plants which are being operated in the country pay in the range of 3.50 to 4.00 Rupees per kg of biomass irrespective of the moisture content. In this analysis 4.00 Rs./kg is taken as the base case and it has been included 3.44% escalability per year.

- Specific cost of power plant

The details of the cost of power plant has been estimated based on the actual cost taken from few suppliers in China (Qingdao Braitway Energy Engineering Co., Ltd.), India (Power Flame India) and South Korea. Also studied the investment done by few local biomass fueled steam turbine base power plants installed in Mahiyanganaya, Girandurukotte area when estimating the specific cost of steam turbine based power plant and 1.3 MUSD/MW has been taken as the base case and 1.6 for gasifier based power plant.

- Operation and maintenance cost (O&M Cost)

Operation and maintenance cost is varying with the capacity of the power plant. Irrespective of the capacity of the power plant, it is essential to maintain a minimum number of staff for keeping the power plant in smooth operation. In this analysis the O&M rate was kept from 15% to 20%.

- Loan repayment period

In general the loan repayment period for the renewable energy power plant in Sri Lanka is 7 years.

- Tax

Taxes for the revenue is 20%. Generally there is no import tax for the renewable energy power plant equipment in Sri Lanka. But need to pay the taxes for the net profit.

2.1.2 Economics Analysis Results

Financial analysis for each technology for different capacities was completed and the results are given in the following table.

Table 2.2: Financial analysis results in each technology options

Parameter	Steam turbine power plant			Gasifier power plant	
Plant capacity - MW	0.6	2.2	3.3	0.6	1.2
House load - MW	0.1	0.2	0.3	0.1	0.2
Capacity at CEB interconnection - MW	0.5	2.0	3.0	0.5	1.0
Specific investment – USD/MW	1.3	1.3	1.3	1.6	1.6
Specific biomass usage – kg/kWh	2.5	2.0	2.0	1.5	1.5
Cost of biomass – Rs./kg	4.0	4.0	4.0	4.0	4.0
Project financing					
Loan – (70%) Rs.	101	370	555	342	683
Equity – (30%) Rs.	43	158	238	147	293
Project IRR - %	22	31	31	27	27
Equity IRR - %	32	50	50	41	41

2.1.3 Sensitivity analysis

Sensitivity analysis has been done for 0.5MW steam turbine based power plant which is the smallest plant in the above analysis and also the lowest IRR indicated.

2.1.3.1 Sensitivity to the cost of biomass

Cost of biomass is varying with the cost of labor, cost of transport and the rate of harvesting. The fuel processing cost (Chipping, storing and feeding) is included to the plant operation cost.

The average yield of the manual harvesting is in the range of 800 to 1000 kg per day per person and the daily pay is approximately 1500 Rs./person.

Transport cost is varying with the mode of transport. If it is a small lorry (Dimo Butta) it can be only loaded upto1000 kgs and the transport would be 2000 Rs. per trip within 25 km radius. The specific transport cost with the small lorry would be 2 Rs./kg of biomass. The specific cost will reduce up to 1.25 Rs./kg for the larger capacity (3 to 5 ton capacity) lorry. Above figures are taken for one time operation.

Since the power plant is operating continuously, biomass is needed continuously and for a dedicated continuous supplier, even with the small lorry, the specific transport cost can be managed approximately around 1.00 to 1.25 Rs./kg. So the analysis has been done taking the above facts in to account and the results are given bellow. The result indicates that the project is only viable only if the cost of biomass is maintained to equal or less than 4.50 Rs./kg

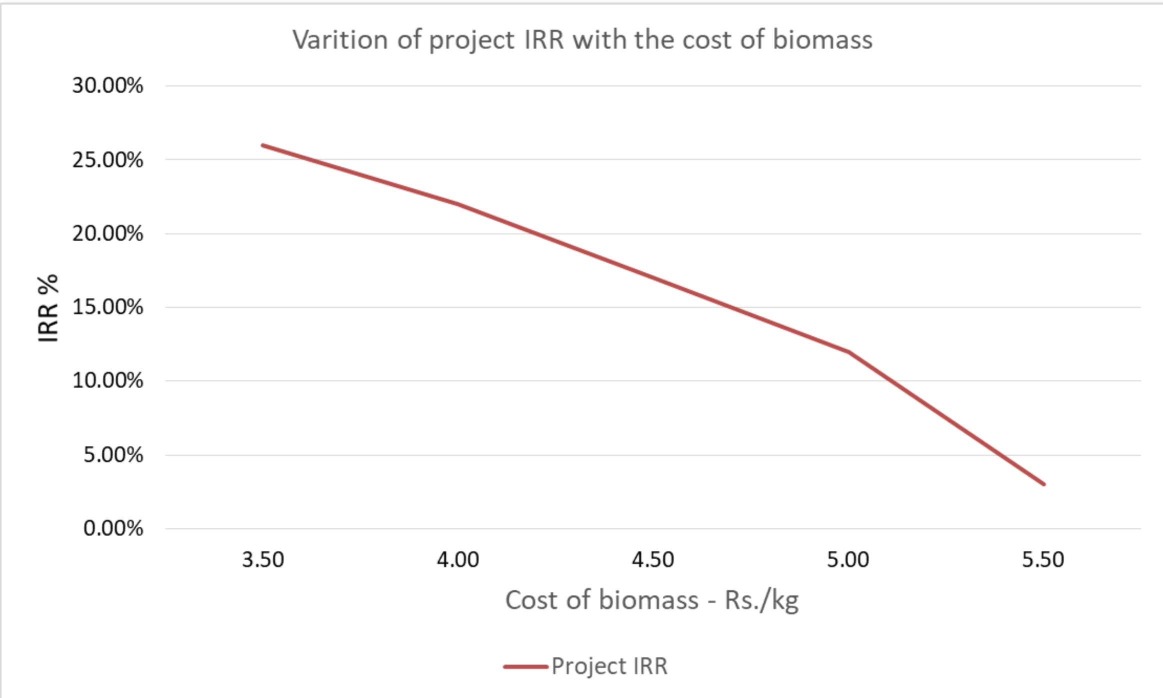


Figure 2.1: Variation of project IRR with the cost of biomass

2.1.3.2 Sensitivity to the specific biomass consumption

Specific biomass use is mainly varying with the moisture content and fresh biomass consisting of approximately 45% to 60% depending on the type of species. Moisture content of fresh Gliricedia is varying from 55% to 60% and this value is maintained at 40% to 45% in other hard wood like Ipil-Ipil, Acacia etc. The high moisture fuel needs to be dry or mixed with low moisture fuel like paddy husk to bring it down to the recommended condition. The above plant sizing has been done based on the 40% moisture and if it is possible to bring it down further, the biomass usage can be reduced and the project IRR can be enhanced. The results of the sensitivity analysis to the specific biomass usage are given in the following figure.

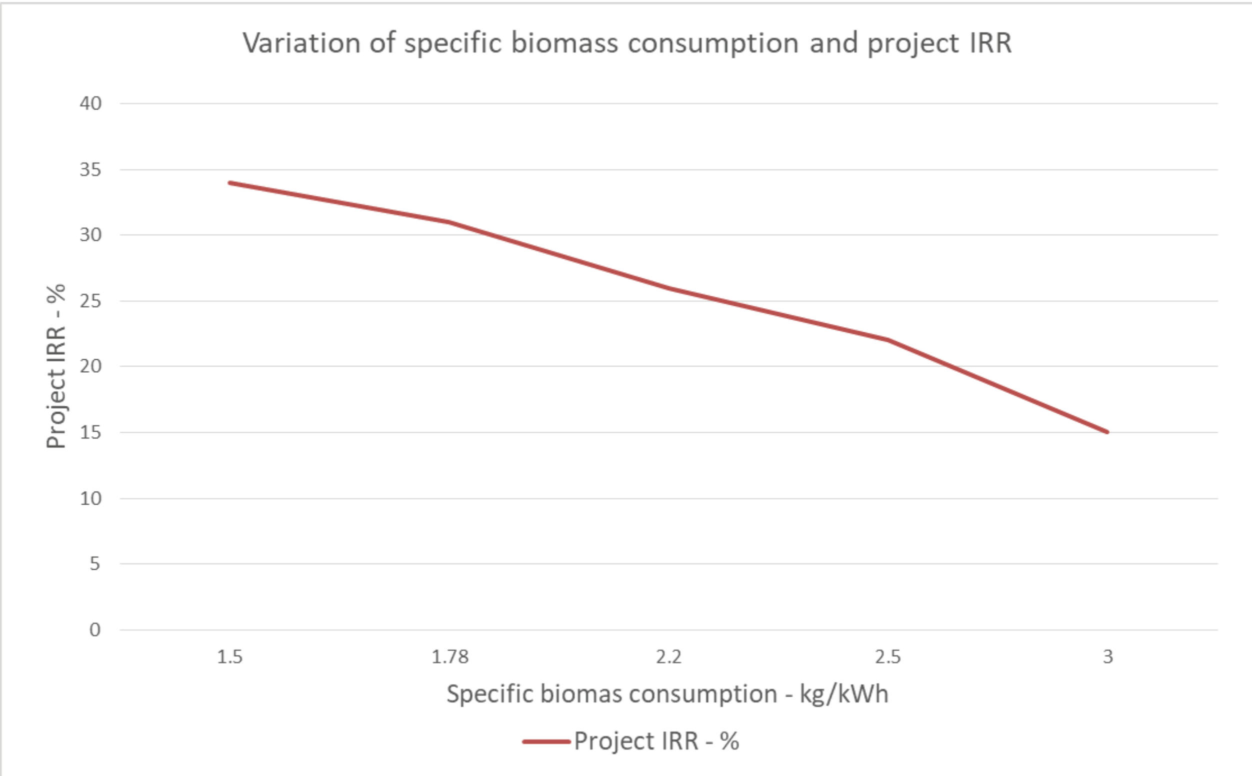


Figure 2.2: Variation of project IRR with the biomass consumption

The above analysis indicates that the specific biomass consumption in the power plant needs to be maintained below 2.5 kg/kWh to make the project successful.

2.1.3.3 Sensitivity to the exchange rate

The existing exchange rate is 182 Rs./USD and this figure has been taken for the base case analysis. The sensitivity has been worked taking in to account 25% increase to the exchange rate and the result is given in the following figure. Even with the 25% increase to the exchange rate, the project IRR is maintaining around 17% and this indicates the capital cost has not given much impact to the project.

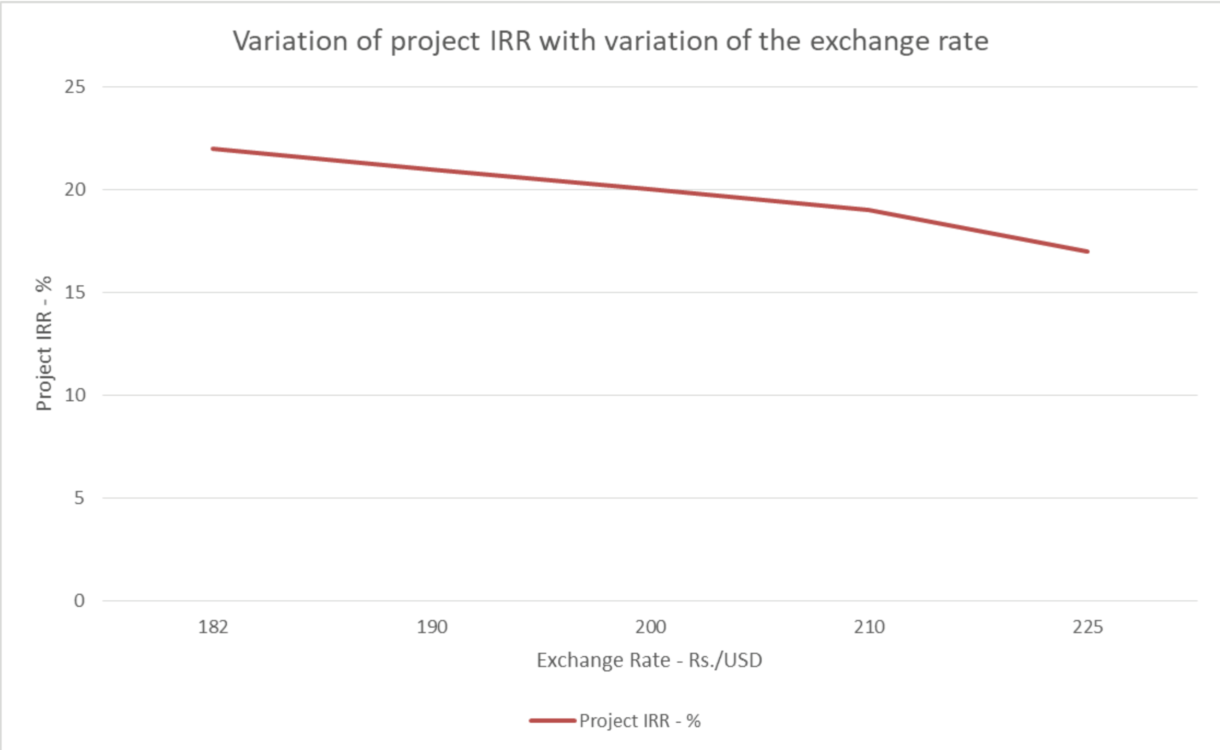


Figure 2.3: Variation of project IRR with the exchange rate

2.1.3.4 Sensitivity to the bank interest rate

Most of the renewable energy projects are implemented with the financial assistance of the bank. The bank loans are limited in these projects and banks provide only the 70% of the total project cost and the balance needs to be provided by the project developer. Different loan schemes had been operating during the past in Sri Lanka maintaining the interest rate below 10% and only one facility is available now with 8% interest. It is limited only for solar projects.

This sensitivity to the equity IRR has been worked considering the variation of bank interest form 7.5% to 15% and the results are given in the following figure.

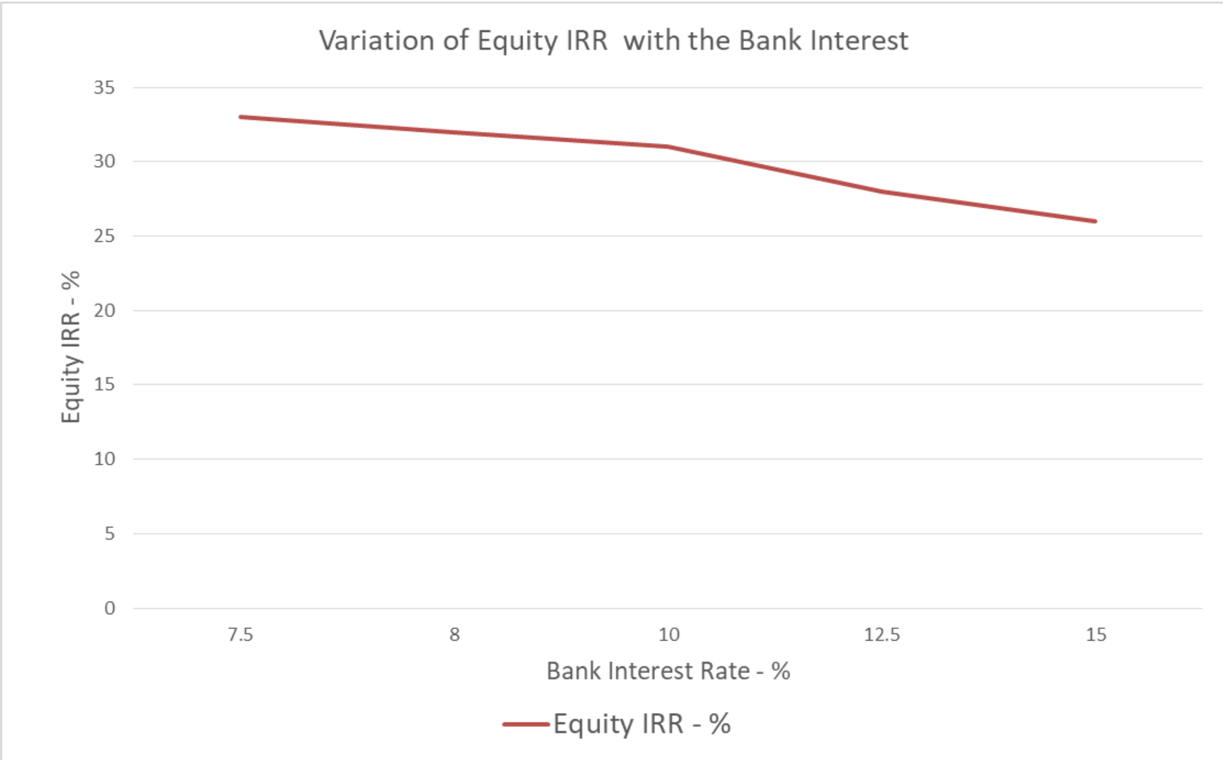


Figure 2.4: Variation of project IRR with the bank interest

The above analysis indicates that the bank interest is not having a considerable impact on the project.

2.1.3.5 Sensitivity to the plant factor

Variation of project IRR has been evaluated changing the operation plant factor of the power plant and the results imply that the plant should be operated keeping the plant factor above 80% to make financially attractive project.

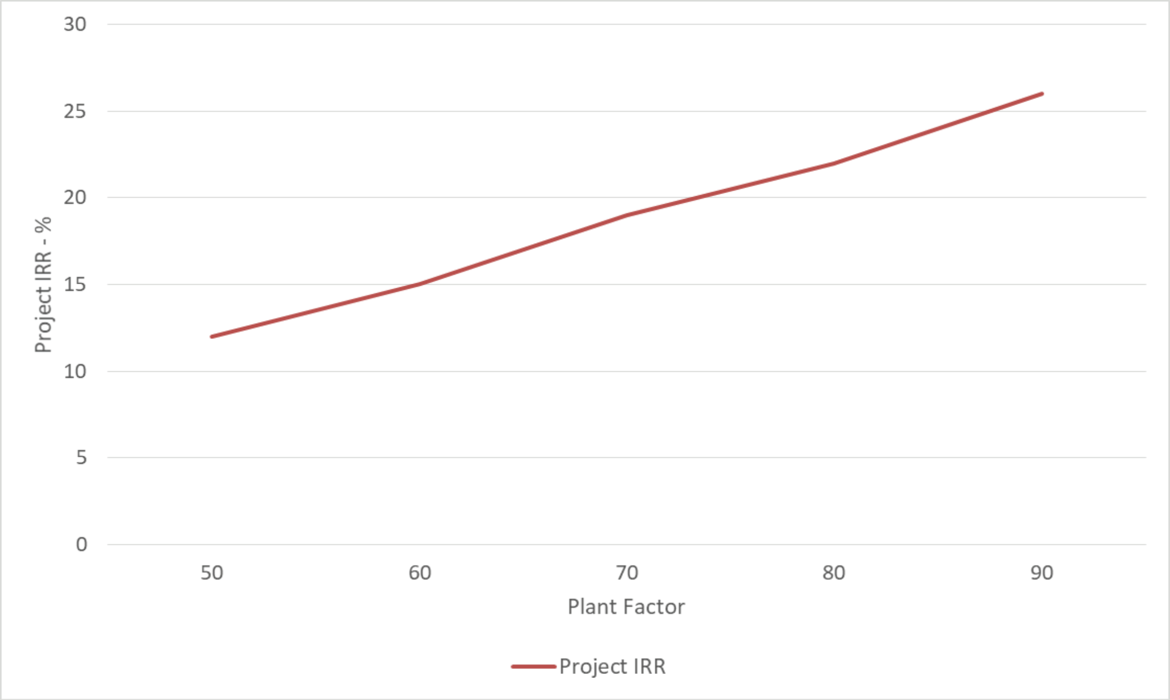


Figure 2.5: Variation of project IRR with the operating plant factor

2.2 Operation and maintenance - Technical expertise is needed

As per the factories ordinance no. 45 of 1942 in Sri Lanka, there should be a certified boiler operator for operation of boiler above the ambient pressure. Three levels of classes have been defined under this ordinance and in a power plant which generates high pressure superheated steam, class one operator is needed.

The level of maintenance can be considered in different levels. These can be categorized as follows.

a. Equipment supplier operates and maintains the heating system
b. In-house operation of heating system with original installer providing maintenance
c. In-house operation of heating system with third party rather than original installer providing maintenance.
d. In-house operation and maintenance of heating system

The advantages, disadvantages and the suitability of the above systems are described in the following table.

Licensed operators are not needed for gasifier based power generation systems, but knowledgeable staff is needed for operation and maintenance.

Option	Suitability	Advantages	Disadvantages
Equipment supplier operates and maintains the heating system	• This is suitable for clients with little or no knowledge of biomass systems operation. • This is a relatively common solution in most of the systems. • Travelling and other logistics of O&M operator should be taken into consideration	• Requires minimal interaction with the biomass system from the site staff. • Should ensure a high-performing system due to a strong knowledge of the technology.	• Is likely to be the highest cost solution. • Offers a low level of control to the client and may cause delays in identifying and rectifying issues due to possible remote nature of contractor.
In-house operation of heating system with original installer providing maintenance	This is suitable for sites with a member of staff, such as facilities manager, who can be trained to operate the system and provide basic checks and maintenance. This is a common solution.	• Lower costs than having everything done by the installer. • May allow more rapid identification of issues and rectifying minor issues. • Offers greater control of system.	• Requires a level of knowledge and training of member(s) of staff. • May result in issues not being spotted or incorrectly rectified.
In-house operation of heating system with third party rather than original installer providing maintenance.	This solution is usually undertaken when the original installer is no longer available/ too costly. As such, it is less common.	• Offers flexibility to choose the contractor. • May result in lower costs and/or better service.	• Care needs to be taken not to void any warranties. • Knowledge level of the system may not be as good as original installer. • May not be capable of the same levels of remote monitoring as the original installer.
In-house operation and maintenance of heating system	This is suitable for a site that has strong biomass capabilities. This is less common and is still usually supported by external contractors in the cases of severe breakdowns.	• Likely to be lowest cost solution. • Offers complete control over operation and maintenance process.	• This may void a System's warranties unless written dispensation is received. • Requires staff with biomass capabilities if good performance is to be maintained

2.3 Factors favoring in implementation of technologies

To identify the factors effecting the implementation of technologies for small scale power generation systems in Sri Lanka, a SWOT analysis has been carried out in order to identify the real situation. The results of the analysis are given below and the summary is given in the following table.

Segment	Strength	Weaknesses
	• Favorable to environment protection • Increase the income and job opportunities in village level • Enhance the renewable energy share in energy mix	• Collection and supply the biomass to the power plant is a complex operation • Initial cost is high • Need trained staff for operation and maintenance • Cost of biomass and the tariff is highly sensitive to the project IRR
Opportunity	SO	WO
• Tax preferences and subsidies • Abundant biomass resources available in home gardens and as an agriculture waste	Peoples needs can be further enhanced	In order to reduce the cost of biomass to the power plant, need to introduce modern techniques for harvesting, transporting and storing.
Threat	ST	WT
• No perfect electricity purchasing policy. There is a conflict between the electricity act and the Sri Lanka Sustainable Energy Authority Acts. Need to solve these issues. • The specific energy requirement in small scale power plants is considerably high.	• Need to solve the conflict between two acts. • Need to enhance the quality of biomass (Mainly reduction of moisture content) before supplying to the power plant or • The quality can be enhance by mixing low moisture agriculture waste such as paddy husk.	Government intervention is needed at this stage since the small scale power plants • Enhance the ambient conditions • Give additional income generation to the villagers • Reduce the energy risk and enhance the energy security

2.3.1 Strengths

- Favorable to environment protection

As there has been an increasing trend in the use of petroleum based fuels – coal and liquid petroleum fuels in the energy sector, GHG emissions in the energy sector have been increasing. In that context, power sector has been identified as one of the key sectors for GHG emission reduction in the future through the introduction of sustainable sources. Accordingly, 20% GHG emission reduction target has been included under the energy sector INDCs, which amounts to 39,383 Gg, from the total GHG emissions of 196,915 Gg for the period 2020-2030 as per the business-as-usual scenario of the Long-Term Generation Expansion Plan 2013-2032 published in October 2013. Out of this, 4% (9,173 Gg) is unconditional reduction and 16% (30,210 Gg) is conditional reduction. Under the category of biomass power generation, it has been identified as 115MW during 2020 and 2030.

- Increase the income and job opportunities

Biomass power plants are usually built near the rural areas having abundant biomass resources. The local farmers/villagers can sell the biomass available in their home garden or waste coming from agriculture farm after the harvest of primary products to biomass power plants directly. This can create job opportunities and increase farmer's income for the local people.

- Enhance the renewable energy share in electricity generation mix.

Since the biomass is produced locally, the energy security in electricity generation can be enhanced. Also the Government energy policy is to generate electricity 100% from renewables by 2050.

2.3.2 Weaknesses

- Collection and supply of the biomass to the power plant is a complex operation

The critical aspect of a biomass power plant is the fuel feed stock that needs to be steady and reliable. The process of supply and collection involves weighing, quality checks, and invoicing, making payments, etc. to numerous suppliers. This operation is highly involving and requires constant attention and dedicated staff.

- Initial cost is high

Due the inherent nature of the biomass energy, the cost of power plants operating from biomass energy is very high. This is due to the additional equipment need for processing fuel, size of the boiler and emission control equipment. As such these power plants due to the nature of the biomass energy are typically very high.

- Need trained staff for operation and maintenance

The operations involved in a biomass power plant are high compared to oil based power plants. Although automation can reduce the number of staff involved, the initial cost of such plants is quite high and as a trade-off between high initial costs, manual operations are needed. Due to the complexity of the operations involved the staff needs to be trained.

- Cost of biomass and the tariff is highly sensitive to the project IRR

The plants are highly sensitive to the cost of the biomass and run the risk of closure if the cost of biomass increases. Shrinking margins would possibly lead to reduction in staff involved and this would bring down the output of the plant which in turn would affect the margins and run into a vicious cycle eventually leading to plant closure

2.3.3 Opportunities

- Tax preferences and subsidies

In Sri Lanka renewable energy technologies are exempt from import and custom duties. This is an advantage the government has granted to investors in renewable energy.

- Abundant biomass resources available in home gardens and as an agriculture waste

An appropriately designed power plant that can run on fuelwood and agricultural waste can minimize the sensitivity to biomass energy, given the abundant fuelwood and agricultural waste in home gardens. Especially in the rural home gardens there is ample supply of fuelwood and agricultural waste due to agricultural activities undertaken by the rural households.

2.3.4 Threats

- No perfect electricity purchasing policy.

Currently power purchasing is carried out by the CEB on a competitive basis. This hinders development of renewable energy power projects as currently it is limited by grid capacity

There is a conflict between the electricity act and the Sri Lanka Sustainable Energy Authority Acts.

- Need to solve these issues.

The SLSEA is responsible for the energy policy of the country and as such gives a direction for energy security of the country by promoting the use of renewable energy. This is not aligned or incorporated in the electricity act and as such technical grid difficulties.

- The specific energy requirement in small scale power plants is considerably high.

Due to the inherent nature of the small scale power plants the specific energy requirement is high due to losses and combustion characteristics. This increases the sensitivity of the plant to biomass energy and puts the plant at risk on cost of biomass energy.

2.4 Case studies available in Sri Lanka

There are few biomass power plants available in the country and the summary of these power plants are given in the following table.

Table 2.3: Summary of the power plants available in Sri Lanka

Name and location of the power plant	Technology	Operating capacity - MW	Biomass supply system	Operating condition
Vidul biomass-Girandurukotte	Steam turbine	3.2	Limited only to Glirecedia and supply by out growers. Separate division is in operation for managing the biomass supply	Operating maintaining the plant factor above 90% continuously.
Mahiyanganaya	Steam turbine	5	Limited only to Glirecedia and supply by out growers	Operating at full capacity
Loggal Oya	Steam turbine	2.5		
Green Watts - Monaragala	Steam turbine	10	Limited only to Glirecedia and supply by out growers	Commissioned on 2018 but not operated continuously at full load due to environmental issues. The system has been designed with 4 modules with 2.5 MW each.
Tokyo Cement - Trincomalee	Steam turbine	18	Running only with paddy husk. The empty lorries come to the plant for loading cement are transported paddy husk to this plant. The cost of transport has been optimized with this logistic arrangement	Running at full capacity. Out of the total capacity 8MW is connected to the national grid
Embilipitiya	Gasifier			
Thirappane	Gasifier	0.5		
Loluwagoda	Steam turbine	5.0		
Ampara	Steam turbine	2.5	Running only with paddy husk. Obtaining paddy husk for continuous operation is a challenge since it is flowing to other users due to price advantage	Not operating continuously.

Out of these power plants operating in Sri Lanka, Tokyo power-Mahiyanganaya, Vidul biomass-Girandurukotte, Loggal Oya biomass power plant, biomass power plant in Mirigama and Tokyo power-Trincomalee are operating at the design plant factor. Others are not in operation continuously due to various reasons. The operating details of the Vidul Biomass – Dehiaththakandiya is given in this report since it is operating keeping the plant factor above 90% from the date of commencing operation to date.

Technical specifications and operating details of the system

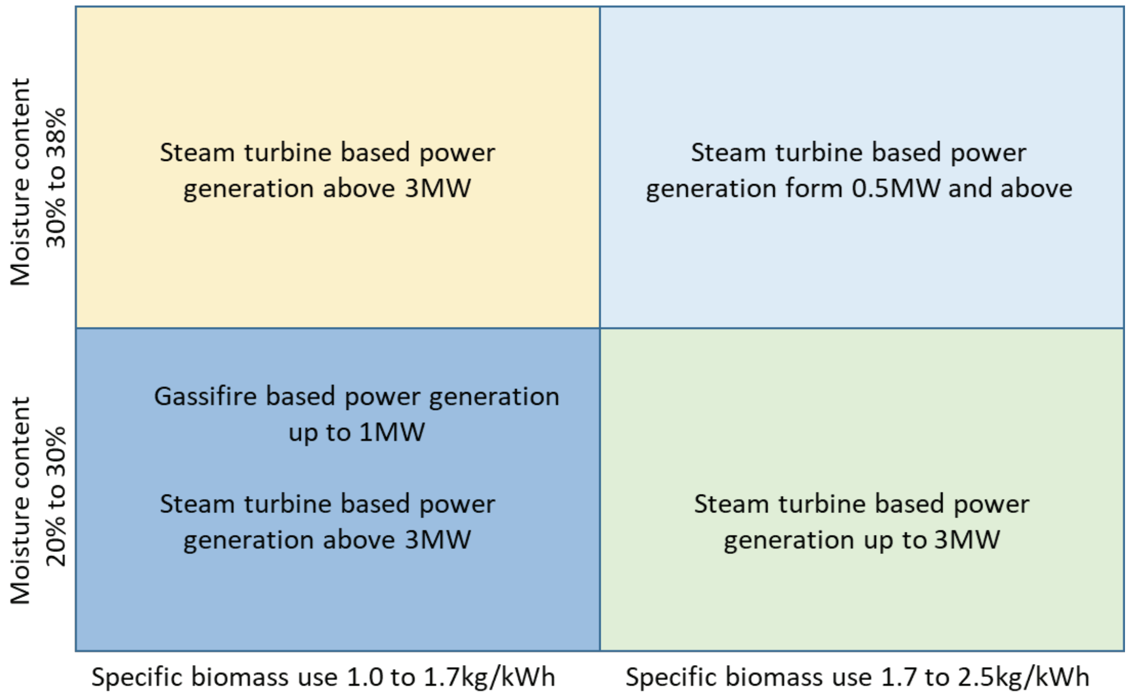
- Type of boiler - Water tube, bi-drum, girth supported, vertical boiler
- Manufacturer of the boiler - ISGEC Heavy Engineering India (Pvt) Ltd
- Boiler evaporation capacity – 16 Mt/hr
- Boiler operating pressure – 40 barg
- Superheated steam temperature – 440 ^{0}C
- Fuel used in the boiler – Gliricedia
- Moisture content of the fuel used – 40% to 45%
  Note – The moisture content of fresh Gliricedia coming in to the power plant is in the range of 55% to 60%. Gliricedia sticks are coming in to the power plant and the sticks are converted in to chips at the power plant. The plant is managing maximum two to three days storage at the plant and during this period the moisture content reduces up to about 45% to 50%. The combustion chamber of this boiler has been designed to feed the chips with 50% moisture maximum, but the biomass usage with this moisture level is higher than the designed values. So they mix paddy husk about 15% to 20% by weight with the wet biomass and the net moisture content of the feeding material is brought down to the range of 38% to 41% and the specific biomass usage is maintained at 1.8 kg/kWh.
- Purchasing price of fresh biomass – 3.75 Rs./kg at the plant gate.
  Note – There is no reputed biomass suppliers registered under this power plant. Anyone can sell the biomass to the power plant and they buy the Gliricedia sticks at the cost of 3.75 Rs./kg at the plant gate and they pay on the spot. Since the plant is paying for biomass without any delay, it is an advantage for the biomass suppliers. Also with this strategy the plant is obtaining the required amount for the boiler without any major difficulty and this plant is operating continuously at 100% plant factor since November 2019 to date (29th February 2020).
- Capacity of the power plant – 3.2 MW
- House load – 400 kW
- Net export to the CEB – 2.8 MW
- Country of origin of steam turbine and the generator. –
- Water source – Water is taken from the stream flowing nearby. Since this is a closed loop system, most of the water is circulating within the system and only the evaporation loses are taken from the stream. The average evaporation loses is 7.5 m^3/hr.

2.5 Selection of most suitable technologies for small scale power plants

As indicated in the above chapters, supply of quality biomass at correct time is the major challenge in small scale biomass power plant operation. To supply high quality biomass to a power plant, intermediate processing is required and it is additional to the fuel cost and sometimes it may not be viable. Considering all these, the following selection criteria are proposed.

Table 2.4: Factor effecting when operating each technology

Parameter	Technology	
	Steam turbine based power generation	Gasifier based power generation
Type of fuel needed	• Multi fuels can be burnt in the combustion chambers of the boilers • Moisture content of the fuel need to be maintained below 38% to get the maximum benefit.	• The fuel with uniform physical parameters is needed. • Can't use multi fuel together • Ideal for fuels like paddy husk, pellets, briquettes etc.
The specific fuel use	• Specific fuel requirement of the system is drastically varying with specification of the boiler and the turbine unit. • The maximum limit for the specific fuel use should be below 2.5kg/kWh. Otherwise the project would not be economically viable.	• The average specific fuel requirement is in the range of 1.5 to 1.8 kg/kWh. • Since the processed uniform fuel is used, this level can be achieved.
The expertise need for the operation	• Need licensed operators for boiler and the turbine.	• No need licensed operators for operation of gasifier. • But skilled operators are needed
Other natural resources needed except fuel wood	• Water is needed for full filling the steam evaporation losses.	• No natural resources are required.
Environmental concerns	• Need to control the fly ash emitting through the stack • Need to have a solution for ash disposal • Noise is generated but can be controlled	• Need to control the fly ash emitting through the stack • Need to have a solution for ash and charcoal disposal • Charcoal is produced during the gasification process. • Noise level is higher than the steam turbine power generation system. But it is controllable.



2.6 Recommendation

The diagram above shows the feasible technologies and capacities against moisture content and specific biomass use that are considered. Small scale steam turbines, below 3MW are feasible for specific biomass use of 1.7 to 2.5 kg/kWh only for moisture content below 30%. Gassifier based power generation is only feasible for specific biomass use of 1.0 to 1.7 kg/kWh and moisture content below 30 %.

Both steam turbines and gasifiers fired from biomass are feasible for small scale power generation if moisture content is controlled to below 30%.

Also, considering the capacity and the operation & maintenance of these power plants, it is suggested to develop at least four power plants in four different locations with total capacity of 2MW by single developer so that the maintenance team can be pooled for four power plants and the operation cost can be optimized.

3. Introduction

Social and environmental impact on small scale power plant operation is discussed in this chapter. These power plants are planned to be established in village level considering enhancing the rural economy. Ten sites have been identified based on the available data and social impact has been assessed to a specified location and same scenario is applicable to the other locations.

Possible environmental issues have been identified under environmental impact assessment and mitigation measures have been discussed.

3.1 Social impact assessment

Before going in to detailed social impact assessment, a suitable site has to be identified. A detailed desk study has been done to estimate the biomass availability selecting a specific location in Ratnapura District for establishment of small scale power plant.

Name of the selected village	-	Thanjanthenna
GPS Coordinates	-	6.638032, 80.863347

The objective of this study is to estimate the biomass availability in home gardens and other agriculture areas in the selected location. The resource area has been demarcated considering 25 km one-way distance on the main roads from this specific location and 1.5 km distance from the main roads to the inside.

Figure 3.1: Biomass supply area for selected specific location

The figure 3.1 indicates the biomass resource area of the selected specific in Ratnapura District. The location is marked in green dots and the red lines are representing the major roads available in this area. Black dotted lines represent the biomass resource area. The latest land use pattern has been taken in to this simulation and it has been done using the GIS software. The simulation was done based on the following criteria.

a. Resource area – 25 km one-way distance from the power plant and 1.5 km for the main road to inside. This figure has been established based on the results of the transport study carried out by "Sustainable Biomass Project" of UNDP, FAO and SLSEA and the sensitivity analysis done for the cost of biomass. With the increase of the resource area, the cost of transport increases so that the project would not be viable. The cost of transport has been limited to Rs. 0.80/kg of firewood.
b. The average yield of the home garden (mixed crop) – 5000 kg/ha per year. This is a very conservative figure compared to the other analysis conducted in Sri Lanka. The renewable energy master plan for Sri Lanka developed by the Asian Development Bank in 2014 indicates that the firewood coming from 500 hectares with mono crops and 1500 hectares with mixed crops is adequate to operate 1MW steam turbine based power plant with 80% plant factor. If it is converted in to biomass the annual generation would be 5750 kg/ha/year in mixed crop lands.

Table 3.1: Land use pattern in the selected biomass resource area

No.	Land Use	Land Area - Ha	Percentage Utilization
0	Built up area	108.99	0.45
1	Barren Land	239.4	1.00
2	Coconut	96.66	0.40
3	Dense Forest	44.14	0.18
4	Open Forest	4,946.84	20.65
5	Forest Plantation	4.96	0.02
6	Grass Land	119.84	0.50
7	Homesteads/Gardens	5,919.15	24.71
8	Reservoirs	1,103.22	4.60
9	Marsh	0.88	0.00
10	Other Cultivation	1,233.41	5.15
11	Paddy	2,873.74	11.99
12	Quarry	17.54	0.07
13	Rubber	150.52	0.63
14	Rock	162.28	0.68
15	Scrub Land	4,886.42	20.40
16	Sparsely Used Crop Land	1,707.73	7.13
17	Tea	342.51	1.43
	Total	23958.23	100.00

c. Percentage of possible collection – 30%. This figure has been estimated based on the specific survey carried out in this area. Very small quantity of firewood is going to the bakeries in this area and few quantities of wooden poles are used in agriculture practices as the supportive structures. Considering all these, this 30% collection factor has been established.

Similar study needs to be carried out before selecting any other locations in the country for establishing small scale power plants.

As per the simulation, the following results were obtained.

Total home garden and sparsely used crop lands	- 7626 ha
Biomass availability	- 45760 Tons/year
Possible collection	- 11440 Tons/year (30% of the total)

This amount is more than adequate to run 1MW of biomass power plant with 85% plant factor.

There are 55 Grama Niladhari divisions in the selected biomass supply area and the total households in this area are 20155. To operate 0.6 MW power plant, 25 tons of fresh biomass per day is needed. The cost of biomass at the plant gate would be 3.75 Rs./kg and with this scenario monthly income to the villagers would be 3.5 Million rupees.

Supply of biomass needs to be organized similar to the green tea leaves collecting mechanism. Assuming 15 intermediate biomass suppliers will join with this power plant, the income will be shared in the following manner.

Table 3.2: Share of income in biomass supply system

Description	Amount – Rs.
Income to the biomass grower	1,836,000.00
Transport	734,400.00
Profit to the intermediate supplier	872,100.00
Total	3,500,000.00

With this scenario the monthly income to the intermediate biomass supplier would be Rs. 55,000.00 to 60,000.00 and the household who supply the biomass will receive Rs. 4000.00 to 6000.00 annually. Generally this biomass comes from pruning in home gardens and agriculture practices and this income is an additional benefit to the villagers. Creation of 600 direct jobs and saving of foreign exchange of 22 million USD per annum is the spillover effect of this initiative with establishment of 40 biomass power plants in different locations in the country with the capacity of 0.5 MW each.

3.2 Specific locations for small scale power plants

A detailed survey on biomass availability has been done by the “Sustainable Biomass Project” in ten districts. Also the agriculture waste potential in some of the areas in the country has been completed. A discussion has been initiated with the Department of Wild Life by the “Sustainable Biomass Project” to remove the invasive species available in Bundala area and convert it in to biomass and supply to the industrial sector. Considering all these details, ten possible sites are proposed to build small scale power plants and the details are given in the following table.

Note: These specific locations need to be further refined in consultation with Ceylon Electricity Board (CEB) based on the availability of absorption capacity in grid substation of the national grid. More details are given in the chapter 4 under legal framework.

Table 3.3: Possible locations for small scale biomass power plants

District	Name of the location	GPS Coordinates
Cluster 01		
Ratnapura	Thanjanthenna	6.638032, 80.863347
Ratnapura	Ambavila	6.520397, 80.710631
Ratnapura	Thimbolketiya	6.412361, 80.795408
Monaragala	Kahakurullanpelessa	6.526564, 81.001856
Ratnapura	Godakawela	6.501112, 80.645753
Cluster 02		
Kurunegala	Hiripitiya	7.653371, 80.370102
Kurunegala	Ganewatta	7.621530, 80.373527
Kurunegala	Rangama	7.572596, 80.366255
Kurunegala	Mahamookalanyaya	7.560631, 80.423208
Kurunegala	Kumbukgate	7.675425, 80.426338

3.3 Environmental impact assessment

Environmental Impact Assessment (EIA) or Initial Environmental Examination (IEA) needs to be carried out for each power plant. The plant capacity and the location where the power plant is going to be established will decide the level of assessment required, either EIA or IEA. The officers of the Central Environmental Authority will carry out a preliminary assessment and will decide the level of detailed assessments required.
However, as per the environmental regulation in force in the country, the following topics need to be addressed during the planning stage.

3.3.1 Common areas that are needed to be addressed for both steam turbine and gasification based power plants

There are few regulations coming under the environmental act no. 47 of 1980 for maximum threshold limit for boundary noise, maximum permissible limits for ambient air quality and maximum permissible limits for stack emission. Also, it is required to address the ash disposal process since both power plants consume biomass partially or fully at their combustion chambers.

- Noise control

According to the regulations made on 21st May 1996 by the Minister of Transport, Environment and Women's Affairs under section 23P, 23Q and 23R of the National Environmental Act, No. 47 1980 read with section 32 of that Act, four major areas have been listed and noise limits have been declared for day and night time. These limits need to be taken in to account when selecting a land for power plant. The level of the noise at the boundary will govern the noise strength of the noise generating source, noise control techniques applied and the distance between noise source and the boundary.

High frequency noise such as noise generating from steam turbine can be easily controlled keeping the machine enclosed. But, low frequency noise with long wave length generating from induced and force draft fans needs to be controlled with proper noise control techniques.

- Stack emission

The National Environmental Act of No. 47 of 1980 specifies regulations for emission levels from stationary sources. For biomass power plants the emissions limits are as follows

Table 3.4: Emission limits for biomass power plants

Fuel	*Rated Output Capacity (C)*	*Type of Pollutant*	*Emission Limit*
Biomass	C<0.5 MW	Particulate Matter (PM) Nitrogen Oxides (NO_x)	Shall be controlled by stack height as set out in Regulation 11
		Smoke	25% Opacity
	0.5≤C<3MW	Nitrogen Oxides (NO_x)	500mg/Nm³
		Particulate Matter (PM)	250mg/Nm³
		Smoke	25% Opacity
	C≥3MW	Nitrogen Oxides (NO_x)	450mg/Nm³
		Particulate Matter (PM)	200mg/Nm³
		Smoke	20% Opacity

For biomass power plants the pollutants being controlled are particulate matter (PM), Nitrogen Oxides (NOx) and smoke.

For power plants with an output less than 0.5 MW, particulate matter and nitrogen oxide needs to be controlled by the stack height as given in regulation 11. Regulation 11 is stated as follows; Minimum stack height of any combustion point source shall be determined by the following equation.

$$C(m) = H(m)+0.6\ Q(m)$$

where H = The height in meters of the tallest building within 5U radius of the point source.

C = Minimum stack height in meters.

U = Uncorrected stack height in meters.

U shall be determined by following equation.

$$U(m)=1.36Q(MW)^{0.6}$$

where Q = Gross heat input in Mega Watt (MW)

(i) This rule shall be applied for the combustion source with gross heat input greater than 0.620MW.

(ii) In any case, stack height shall not be less than 20 meters except for the combustion sources with gross heat input less than 0.620 MW.

For power plants between 0.5 MW and 3 MW, emissions level for particulate matter, nitrogen oxide and smoke from the stack should comply with levels given in the table above

- Ambient Air Quality

The regulation for ambient air quality had been amended in 2008 and the schedule is as follows

Table 3.5: Ambient air quality limits

Pollutant	*Averaging Time**	*Maximum Permissible Level*		*+ Method of measurement*
		μgm^{-3}	*ppm*	
1. Particulate Matter - Aerodynamic diameter is less than 10 μm in size (PM_{10})	Annual	50	—	Hi-volume sampling and Gravimtric or Beta Attenuation
	24 hrs.	100	—	
2. Particulate Matter - Aerodynamic diameter is less than 2.5 μm in size ($PM_{2.5}$)	Annual	25	—	Hi-volume sampling and Gravimtric or Beta Attenuation
	24 hrs.	50	—	
3. Nitrogen Dioxide (NO_2)	24 hrs.	100	0.05	Colorimetric using saltzman Method or equivalent Gas phase chemiluminescence
	8 hrs.	150	0.08	
	1hr.	250	0.13	
4. Sulphur Dixoxide (SO_2)	24 hrs.	80	0.03	Pararosaniliene Method or equivalent Pulse Flourescent
	8 hrs.	120	0.05	
	1hrs.	200	0.08	
5. Ozone (O_3)	1 hr.	200	0.10	Chemiluminescence Method or equivalent Ultraviolet photometric
6. Carbon Monoxide (CO)	8 hrs.	10,000	9.00	Non-Dispersive Infrared Spectroscopy"
	1 hr.	30,000	26.00	
	Any time	58,000	50.00	

At any time in the site of the power plant the ambient air quality should meet the above standards for the above pollutants

- Ash disposal

At present there are no standards for disposal of ash. However with the trend that farmers are moving away from chemical fertilizers, ash offers a good source of mineral enrichment to the soil. For small scale biomass power plants, ash generation is small and can be managed by offering it free of charge to farmers through the supply chain network for biomass.

Ash generation from combustion of biomass is on average around 2 % by weight of biomass. For a typical small scale biomass power plant the average daily biomass consumption is around 25 MT. This means the daily ash production is around 500 kg and this amount of ash can be easily be distributed to farmers to be used as fertilizer.

In gasification power plant, char is the final product after gasification process and char is very valuable product in agriculture mainly for controlling bacteria and fungus.

Figure 3.2 Figure 3.3

Figure 3.2: Char comes out from the biomass gasification system

Figure 3.3: Ash comes out after completing the biomass combustion

3.3.2 Specific areas to be addressed for each technology

Water supply to the steam turbine power plants is a critical aspect for operation of the plant. Quality of water is an important factor for steam turbines based power plant. Generally a RO treatment plant is needed to remove all dissolved solids to treat the water to the required quality needed by the steam turbine.

Quantity of water is as important to ensure that the plant has the required amounts. If bore-wells are the source of water then it is important to carry out the yield and production tests for these wells. The quantity of water required for the plant on a daily basis should be inquired from the supplier of the steam turbine

CHAPTER 4: LEGAL FRAMEWORKS RELATED TO SMALL SCALE BIOMASS POWER PLANT IN SRI LANKA

4 Introduction

Biomass is a renewable resource that is primarily based on organic matter as a fuel related to plants, vegetation and waste that generates from agricultural and industrial process as a by-product or residuals. Growing biomass as a fuel for Dendro power generation gained attention in the recent past and at the end of 2019 total biomass based electricity generation capacity is 38.7 MW including both Dendro and agriculture waste based power generation. Evidently, the growth of the biomass capacity in the past has not achieved the planned progress providing firm capacity to the grid. The biomass power plants have been treated as dispatchable power plants in the planning process and expected to grow in capacity in the planning period. Further capacity additions shall be considered project by project depending on the feasibility of implementation.

There are no restrictions on the capacity of the biomass plant and same rules and regulation that apply for the large scale power will apply. This means getting the necessary clearances from the SLSEA and the Central Environmental Authority. These clearances will ensure that the plant does not violate and complies with existing environmental regulations

4.1 Obtaining the energy permit

Establishment of an electricity generation power plant and selling electricity to the national grid is governed by Sri Lanka Electricity (Amendment) Act no. 31 of 2013 and Sri Lanka Sustainable Energy Authority Act no. 35 of 2007. Before the Sri Lanka Electricity (Amendment) Act was enforced in 2013, the grid connected small scale power plants (less than 10MW) were solely governed by the Sri Lanka Sustainable Energy Authority Act and the electricity was purchased to CEB through a specified Non-Conventional Renewable Energy (NCRE) Tariff system. An energy permit was issued by SLSEA after completing the approval process which follows numbers of steps.

The first step of this approval process was submitting an application to SLSEA and registering it in the general registry and obtaining a registration number. Since the applications were entertained on a first come first served basis, this number was very important in this process. After receiving the application, a review was done by SLSEA staff and if it is in line with the renewable energy development guide lines, this application was sent to CEB requesting the grid interconnection proposal. If the grid space was available for this project, CEB issued the grid interconnection proposal and upon receiving that letter SLSEA issued a provisional approval. Upon receiving the provisional approval, all the other approvals including environmental clearance were taken by the project developer and after successfully completing this process the energy permit was issued by SLSEA.

After the Sri Lanka Electricity Act was enforced in 2013, this process was completely changed and the project developers are selected based on the competitive bidding process. First, the CEB evaluates each grid substation to understand the possibility of interconnection for each NCRE technology and the capacities. Also, the capacity addition in each technology should be in line with the "least cost long term generation expansion plan" published by CEB. After obtaining this information, CEB will publish the request of proposals (RfPs) for selecting the prospective NCRE developers for different technology options. The RfPs are published for selected grid substations and for selected technology and capacities. The developers who are selected through this process need to forward an application to the SLSEA for obtaining the energy permit. Since most of the preliminary requirements (evaluation of the proposals and grid interconnection proposals) have been completed during the RfP process, SLSEA issues the provisional approval at this stage and as in the previous process, approval process needs to be completed by the developer and once it is successfully completed, SLSEA issues the energy permit. But before issuing any permits, the relevant site should be on gazette as an energy development area under the provision given by SLSEA Act.

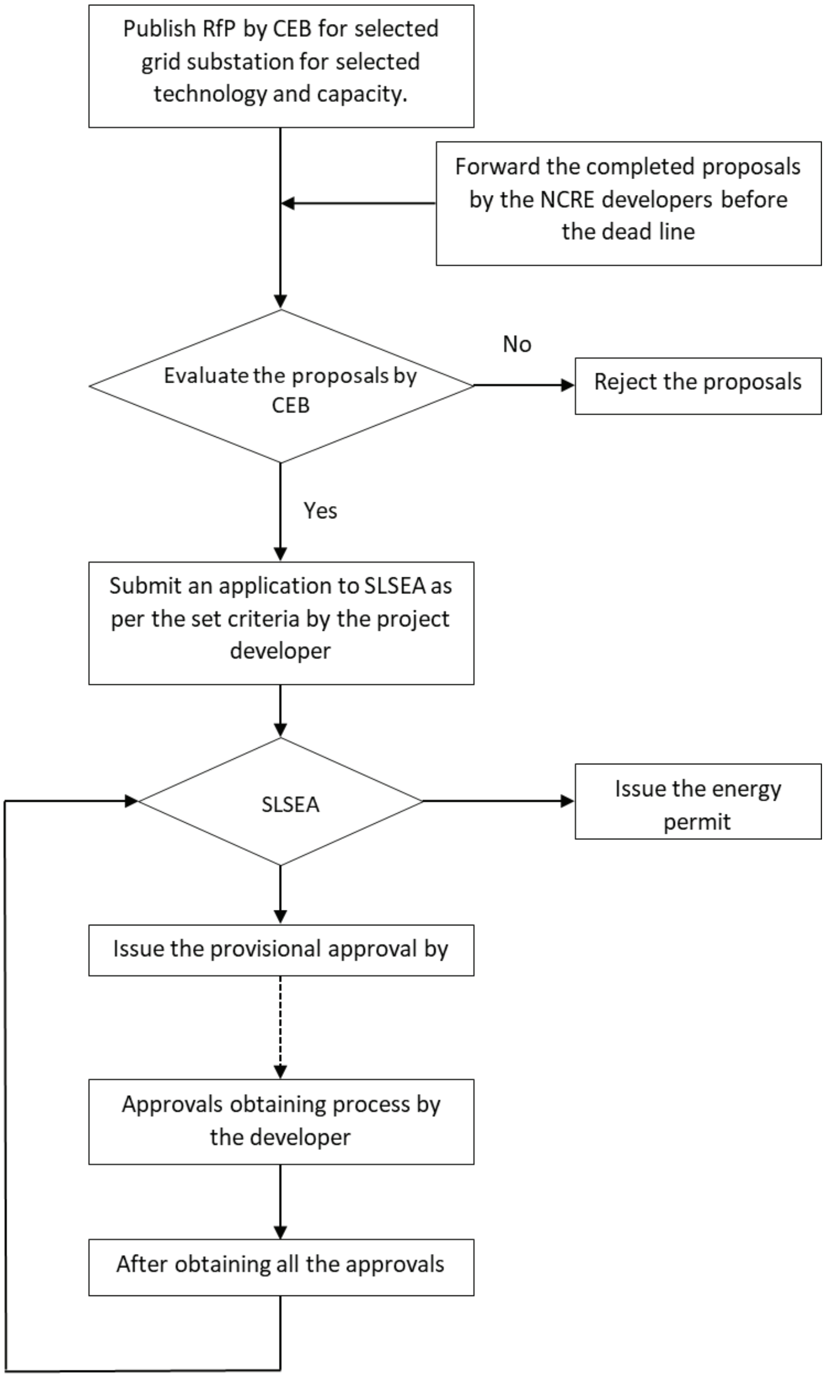


Figure 4.1: NCRE Project approving mechanism in operating for competitive bidding process.

4.2 Energy development area

All the renewable energy projects need to declare and on gazette as an energy development area under the provisions given in section 12 of Sri Lanka Sustainable Energy Authority Act. The definition of the project area is varying in type of sources. Mini hydro project area means the weir, powerhouse and the section in between. Wind project means the turbine footing area and similarly the biomass project area means the biomass supply area, water supply area and the power plant location. The resource is secured when a project falls in an energy development area and no one can use it for other purpose.

4.3 Signing standard power purchasing agreement (SPPA)

The standard power purchasing agreement is signed between the project developer and CEB after obtaining the energy permit. The validity period for a SPPA is 20 years and the tariff is decided through a competitive bidding system.

4.4 Obtaining energy generation license

After obtaining the SPPA, it is required to obtain the energy generation license for the project from Public Utilities Commission of Sri Lanka (PUCSL). If all the processes up to signing of SPPA have been completed correctly, obtaining the generation license is not a difficult task.

5 Introduction

As per the Sustainable Energy Authority Act, the capacity of a small scale power plant is limited to 10MW. There can be numbers of modules if the capacity increases this limit. After establishing the SLSEA in 2007, the interest to establish small scale biomass power plants have come in to the field, and the first power plant under this scheme was established in Mahiyanganaya with the capacity of 5MW. After that few biomass power plants came in to operation in different areas of the country, but the capacity of most of these plants were limited to less than 10MW except 10MW plant at Tokyo Cement Trincomalee operating with paddy husk.

The paddy husk supplying strategy of Trincomalee power plant is little different to the others. They use the same Lorries for loading cement and for transporting paddy husk from different parts of the country. With this logistic arrangement, the cost of transport has been optimized.

One power plant with the capacity of 10MW running with Glirecedia has been established in Kumbukkana, Monaragala but it is not operating continuously at full load. This is mainly due to environmental and biomass supply issue. Also, this power plant has been designed in modular basis with 2.5MW in each module. This is mainly for optimizing the operating efficiency when fluctuating the biomass supply.

The power plant at Girandurukotte with 3.2MW is operating continuously with Glirecedia and their strategy is paying for biomass at the plant gate. Since the biomass can be converted in to cash instantly when transporting to power plant, people try to get this benefit to cater their day to day expenses.

Considering all the above scenarios, it has been noticed that the supply of the biomass at correct time is the major issue in power plants. With this background, it has been decided to scale down the capacity of a power plants and to go with minimum 0.5MW considering the technology available in the world. The plants can be established scattered in suitable geographical locations in the country considering the availability of biomass.

5.1 Flow of feedstock from source to plant and economical distance

The diagram illustrates the biomass flow from the plant gate to the combustion chamber. This section discusses the flow of biomass from the farmer to the plant gate and also from the plant gate to the combustion chamber

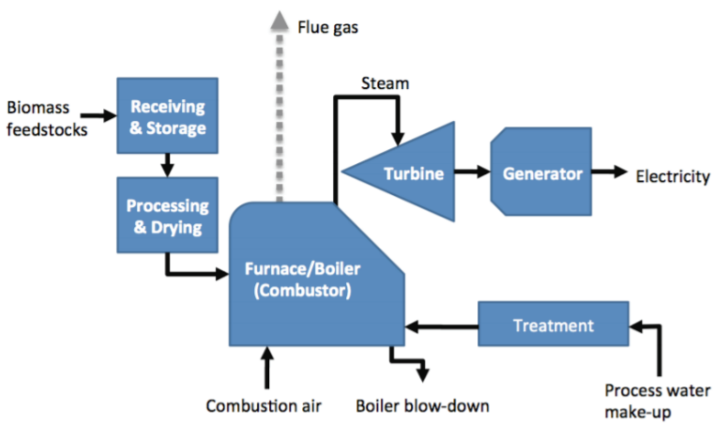


Figure 5.1: Flow of biomass inside a power plant

Government has published a standard (SLS 1551) for ensuring the sustainable biomass in 2018 and all the biomass suppliers need to follow this standard when supplying biomass to small scale power plants. As analyzed in the section 3 the economical distance for collection of fuelwood for the site considered is 25 km from the power plant and 1.5 km distances from the main road, collected by small trucks with a payload of around 750 kg. The transport cost for this mode of collection is 0.8 Rs/kg. These figures are site and terrain specific but can be used as a guide to understand the distances, modes of transport and specific cost of transport involved. The diagram below illustrates the supply chain for the proposed modality, where a middleman, who is also involved in transporting the biomass to the power plant, works with a group of farmers or households. The middleman collects the biomass from a group of farmers or households. Due to the low production amounts involved from a single farmer, transporting directly to the power plant by the farmer is not profitable. This collection system is efficient for collecting even small amounts of fuelwood from farmers remote from the main road.

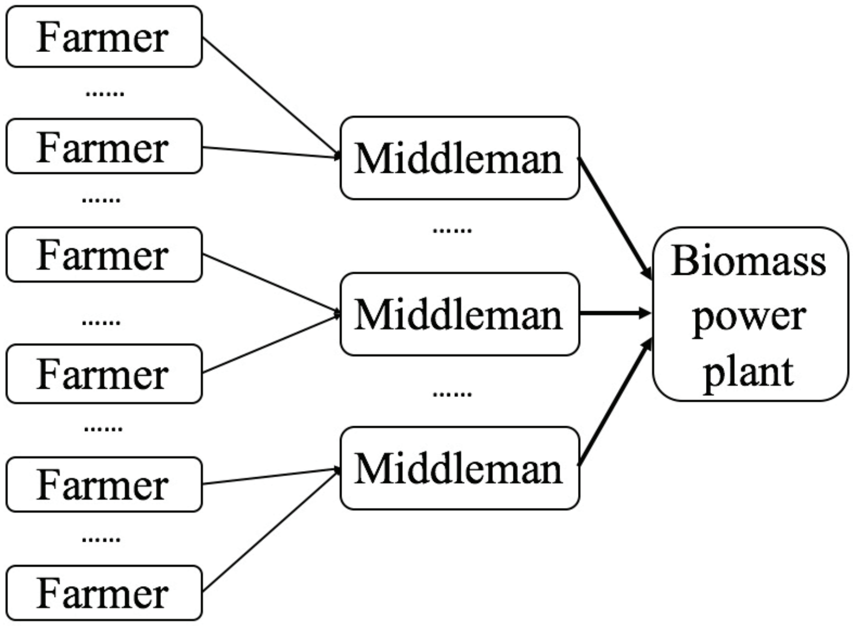


Figure 5.2: Flow of biomass from source to power plant

However with larger payload trucks of 3-5 tons the collection distance from the power plant could be increased to about 80 km without affecting the transport cost per kg.

For the supply chain to be successful the plant should operate a weigh bridge, so that all vehicles supplying biomass are weighed.

The plant should be designed to operate on a mix of fuelwood and agricultural waste like rice husk, saw dust etc. This will enable the plant to become less sensitive to price changes in fuelwood and also become less dependent on fuelwood.

Price paid to the fuelwood supplier should account for the moisture content. A slightly higher price can be paid for dry fuelwood and slightly lower for wet or freshly harvested fuelwood.

5.2 Processing

All processing whether chipping or drying should be carried out at the plant to reduce costs. By stacking to accommodate drying the biomass can be dried to desired levels to reduce specific biomass consumption. To reduce drying at the plant a higher price can be offered to those supplying dry fuelwood and a lower price for freshly harvested biomass.

If chipping is involved the plant should size the chipper so that the daily requirement is processed in eight hours. So for a daily requirement of 25 tons a chipper capacity of 4-5 tons per hour is recommended.

For power plants a disc type wood chipper is recommended, as this technology is better for this kind of application

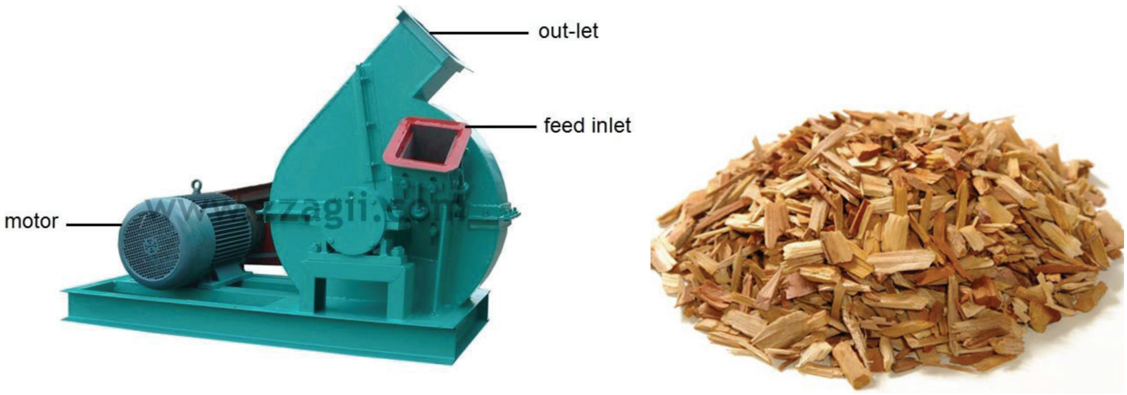


Figure 5.3: Biomass chipper and chipped wood

The cost of a chipper with the capacity of 4 – 5 tons per hour would be around 4 million rupees and the processing cost would be 0.15 Rs./kg. These figures have been taken in to account for the financial and sensitivity analysis done in chapter 2.

5.3 Storage needs

To operate a small scale power plant, one week of storage at the plant is sufficient to keep down the working capital tied down to storage. Given the scale of biomass needed at typically around 25 metric tons per day, the risk of supply chain failure is low and this amount of supply can be conveniently sourced without any interruptions to the operation of the power plant. So investing in a large storage is unnecessary.

The storage area should be well ventilated, covered from rain and well drained to prevent moisture build up.

Figure 5.4: Biomass storage

Fuelwood should be stacked to allow the air flow
For a 25 tons per day fuelwood consumption following are the dimensions of a storage needed for a weeks' storage

Total weekly storage tonnage	= 175,000 kg
Weight of a cubic meter of fuelwood	= 300 kg
Total volume of fuelwood	= 583 cubic meters
Assuming stack height of 2 meters	
Dimensions of storage area	= 51 feet by 51 feet

5.4. Cost of fuel (Cost breakdown)

The breakdown below is for a collection modality explained in section 3. The breakdown is site specific and this breakdown is a guide to the pricing. Also, this cost structure is given for fresh biomass. The moisture content of fresh biomass is varying from 42% to 60%. For an example fresh matured biomass contain approximately 42% moisture and less matured Glirecedia stems contain about 60% moisture. So, these figures propose that irrespective of the moisture content and whatever the fresh material that it is entertained at the plant gate at weight basis.

Price paid to grower per kg	= Rs 2.00
Cost of transport per kg	= Rs 0.80
Profit by intermediary per kg	= Rs 0.90
Price at plant gate per kg	= Rs 3.75
Cost of processing per kg	= Rs 0.15
Cost of biomass at combustion per kg	= Rs 3.80

These figures have been estimated based on the details taken from two power plants in Mahiyanganaya and Dehiaththakandiya area.

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