CHAPTER 3

FEASIBILITY ANALYSIS OF PV-BIOMASS HYBRID SYSTEM FOR TEXTILE INDUSTRIES

3.1 INTRODUCTION

Renewable energy systems have been gaining more importance in developing countries not only due to the increase in concern towards environmental sustainability but also resolving the looming energy crisis that bewilders economic development. In this chapter, a sustainable and clean hybrid renewable energy system is proposed to meet the energy demand of the industries of TamilNadu, India. Industries have been key drivers of electricity consumption in the past decade and integration of renewable energy sources to the industrial sector has not yet been addressed. This chapter focuses on the economic and environmental sustainability of the selected hybrid renewable energy system to replace the conventional grid system. The economic sustainability analysis for small scale industries, especially textile industries is performed using Hybrid Optimization Model for Electric Renewables (HOMER) software. The financial analysis is performed with the help of economic indicators and the environmental sustainability is analyzed with the help of Clean Development Mechanism. The possible solutions to the barriers in the implementation of the biomass based hybrid system are discussed by performing the post-sustainability analysis.

3.2 METHODOLOGY

This chapter focuses on the feasibility of small scale decentralized power generation for textile industries through hybrid RE sources and sustainable development of such RE sources. The feasibility study is carried out
in three phases: Pre-feasibility analysis, Sustainability and Post-Sustainability analysis and the framework of the feasibility study is depicted in Figure 3.1.

M/s. Auro Mira Bio Energy Madurai Limited (AMBEMIL) is an existing grid connected Biomass plant that has been the source provider of the data required for the feasibility study. AMBEML has implemented 10 MW Biomass power plant at T.Kallupatti village in the Madurai district of Tamil Nadu. The fuels used for the power generation are juli flora, bagasse, groundnut shell, paddy husk, plywood waste and coconut fibre. The project activity registered for CDM employs the Rankine Cycle technology for the power generation process.

Figure 3.1 Framework of the feasibility study

The basic technology involved is the direct combustion of biomass through a multi-fuel fired boiler to generate a high-pressure and high-
temperature steam. The relevant data needed for the initial assessment and sustainability analysis has been obtained from AMBEM.

All of the renewable sources depend on different factors-apart from seasonal or even hourly changes. While the amount of solar energy available is dependent on climate and latitude, the wind resource on atmospheric circulation patterns and geographic aspects. The resources dependence of various factors in turn influences how much power can be generated and thus the behaviour and economics of the hybrid system. As a consequence, in the pre-feasibility study, a detailed assessment of the available resources in the chosen region, industrial load demand, costs of the chosen RE technologies and fuel viability assessment have been carried out. In the Sustainability analysis phase of the study, techno economic analysis and environmental impact of the hybrid RE technology through CDM has been discussed. The techno-economic analysis of biomass based system has been performed using HOMER software package to identify the optimal hybrid system configuration to meet the demand of the textile industry. The analysis is based on Net Present Cost (NPC) and Cost of Energy (COE) which includes capital cost, fuel cost and O&M cost. The financial analysis of the hybrid system is performed based on the economic indicators of sustainability. The possible GHG emission reductions with the adoption of CDM and carbon credits are computed in the environmental analysis phase. The micro and macro-economic impacts that would influence the future sustainability of such RE projects have been discussed in the Post- sustainability study phase.

3.2.1 Pre-Feasibility Analysis

In this section, an initial assessment of the available resources, cost and demand of the textile industry is accomplished to analyze the techno-economic viability of biomass based hybrid renewable energy systems using HOMER tool. This initial assessment is carried out outside HOMER and data is fed into the software. HOMER simulation software provides optimized results of
the hybrid system by performing thousands of simulations based on input parameters like resource inputs, primary load inputs of the chosen renewable energy sources, fuel price and costs per unit for various components of the proposed hybrid system. All the parameters are explained in the subsequent subsections.

3.2.1.1 Resources availability

Solar and Biomass are the renewable energy sources considered in the study because of the enormous resource availability. The solar energy resource data for the textile mill with 9.66°N Latitude and 77.79°E Longitude are obtained from NASA website (NASA Surface Meteorology and Solar Energy) and it is found that the daily global solar irradiation is 4.86 KWh/m² on an average, which means that there is enough solar potential and considerable amount of solar energy can be obtained throughout the year. The monthly insolation data are fed as solar resource inputs in the HOMER tool for the feasibility study of the Biomass plant in the chosen region. The tool calculates the clearness index for the corresponding solar radiation. The amount of solar radiation that strikes the top of the atmosphere anywhere on earth can be calculated with just the latitude. Hence, if the amount of radiation striking the surface is specified, HOMER immediately divides that by the amount of radiation striking the top of the atmosphere to calculate the clearness index. The solar radiation profile for one-year period is shown in Figure 3.2.

Biomass is the prominent source of energy for the textile mill because agriculture is the highest grosser in and around T.Kallupatti block. There are about 39 revenue villages in the block. Cotton, rice, maize, jowar, groundnut and coconut are being grown extensively there. Juliflora, Bagasse, Ground Nut Shell,
Paddy Husk, Plywood waste and Coconut Fibre are the fuels purchased by AMBEMIL, whose average monthly biomass feedstock availability during the year 2012 have been entered as biomass resource inputs in HOMER tool. Figure 3.3 shows the biomass resource inputs in tons per day for the chosen region.

Figure 3.2 Solar radiation profile for Kallupatti block

Figure 3.3 Biomass resource inputs in tons per day
3.2.1.2 Load profile

The textile industry operates round the clock except during plant maintenance. The load type used is AC. The average daily load is scaled to be 49 MWh with 4 MW peak and is used as load inputs in HOMER tool. The approximate seasonal load profile of the textile mill is given in Figure 3.4.

![Seasonal load profile of the textile mill](image)

**Figure 3.4 Seasonal load profile of the textile mill**

3.2.1.3 Component costs

HOMER tool also requires economic inputs of RES components for performing the simulation. The PV panels are connected in series. The selected make of the PV model is U5P 80, the cost of which are specified in the tool. The capital cost and replacement cost for a 1 KW SPV is taken as $6000 and $5000 respectively. As there is very little maintenance period of 1 or 2 days required for dust clearing on PV panels, only $10/year is taken for O&M costs. The lifetime of PV panels is 20 years. The PV derating factor is chosen as 90% to account for any discrepancy between the rated performance and the actual performance of the module due to dust, temperature, shading, snow cover, aging, wiring losses etc. The investment cost, replacement cost and the O&M cost of 1 MW biomass plant is about 1 M$, 0.8 M$ and 0.01$/h respectively. The lifetime of the project is 25 years. The model constraints include maximum annual capacity shortage varying from 0% to 10%. The capital cost, replacement cost, O&M costs of a 1 KW DG are taken as $1200, $1000, and $1.03/h respectively. The prices considered are the data obtained from local Indian manufactures and distributors.
3.2.1.4 Fuel viability

Fuel viability indicates the appropriate quantity and quality of the fuel for feeding the boilers of the power plant. In order to ensure continuous power supply for the textile mill, biomass fuel viability has to be ascertained. The fuel quantity can be determined by the biomass surplus estimation in the selected region. The estimation of surplus biomass is needed in pre-feasibility study for the implementation of biomass based projects. The data regarding consumption of biomass fuel types in the power plant obtained from AMBEML is shown in Table 3.1.

**Table 3.1 Consumption of biomass fuel types in AMBEML**

<table>
<thead>
<tr>
<th>Month/Year</th>
<th>Juliflora (1000 tons)</th>
<th>Bagasse (1000 tons)</th>
<th>Paddy Husk (1000 tons)</th>
<th>Plywood Waste (1000 tons)</th>
<th>Groundnut Shell (1000 tons)</th>
<th>Coconut Fibre (1000 tons)</th>
<th>Gross electricity generated (MWh)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Jan/2012</td>
<td>4.068</td>
<td>1.248</td>
<td>1.895</td>
<td>0.086</td>
<td>0.010</td>
<td>2.398</td>
<td>5286</td>
</tr>
<tr>
<td>Feb/2012</td>
<td>2.771</td>
<td>1.401</td>
<td>0.643</td>
<td>0.078</td>
<td>0.015</td>
<td>2.292</td>
<td>3890</td>
</tr>
<tr>
<td>Mar/2012</td>
<td>3.762</td>
<td>1.459</td>
<td>0.751</td>
<td>0.059</td>
<td>0.087</td>
<td>1.751</td>
<td>4298</td>
</tr>
<tr>
<td>Apr/2012</td>
<td>5.913</td>
<td>0.987</td>
<td>1.057</td>
<td>0.115</td>
<td>0.126</td>
<td>1.192</td>
<td>6190</td>
</tr>
<tr>
<td>May/2012</td>
<td>5.213</td>
<td>2.013</td>
<td>0.908</td>
<td>0.090</td>
<td>0.034</td>
<td>1.786</td>
<td>5986</td>
</tr>
<tr>
<td>June/2012</td>
<td>5.068</td>
<td>1.099</td>
<td>0.906</td>
<td>0.137</td>
<td>0.064</td>
<td>1.588</td>
<td>5207</td>
</tr>
<tr>
<td>July/2012</td>
<td>3.630</td>
<td>0.940</td>
<td>1.908</td>
<td>0.028</td>
<td>0.081</td>
<td>1.515</td>
<td>4962</td>
</tr>
<tr>
<td>Aug/2012</td>
<td>4.230</td>
<td>0.665</td>
<td>1.628</td>
<td>0.110</td>
<td>0.067</td>
<td>1.178</td>
<td>5296</td>
</tr>
<tr>
<td>Sep/2012</td>
<td>3.512</td>
<td>0.644</td>
<td>1.326</td>
<td>0.168</td>
<td>0.039</td>
<td>1.084</td>
<td>4306</td>
</tr>
<tr>
<td>Oct/2012</td>
<td>3.980</td>
<td>0.081</td>
<td>0.641</td>
<td>0.188</td>
<td>0.000</td>
<td>1.153</td>
<td>4139</td>
</tr>
<tr>
<td>Nov/2012</td>
<td>3.839</td>
<td>0.000</td>
<td>0.428</td>
<td>0.070</td>
<td>0.015</td>
<td>1.826</td>
<td>4361</td>
</tr>
<tr>
<td>Dec/2012</td>
<td>4.132</td>
<td>0.146</td>
<td>0.690</td>
<td>0.549</td>
<td>0.020</td>
<td>3.139</td>
<td>5292</td>
</tr>
</tbody>
</table>

Biomass available in the region is found to be 742,078 tons/year. The biomass consumption in the region is 340,990 tons/year and that of the project activity (AMBEMEL) is 111,983 tons/year. The surplus biomass is estimated by subtracting the total consumption from the biomass available and is found to be 289,105 tons/year. Biomass availability is 64% greater than biomass consumption including the project activity and the gross electricity generation is
51,800 MWh annually. Hence continuous supply of biomass fuel for the off-grid power generation is ensured.

Fuel quality requires to be established by the laboratory scale estimation of the fuel values like Specific Fuel Consumption (SFC), Calorific Value (CV) and their costs. These values are estimated by the existing plant, AMBEML. The fuel values obtained from AMBEML for the analysis are given in Table 3.2.

<table>
<thead>
<tr>
<th>S.No</th>
<th>Type of Biomass fuel</th>
<th>SFC (Kg/KWh)</th>
<th>Calorific Value (MJ/Kg)</th>
<th>Cost per ton ($)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Juliflora</td>
<td>1.34</td>
<td>21.5</td>
<td>38.5</td>
</tr>
<tr>
<td>2</td>
<td>Ground Nut Shell</td>
<td>1.12</td>
<td>20</td>
<td>27.7</td>
</tr>
<tr>
<td>3</td>
<td>Bagasse</td>
<td>2.25</td>
<td>15.54</td>
<td>30.7</td>
</tr>
<tr>
<td>4</td>
<td>Coconut Fibre</td>
<td>1.15</td>
<td>19.69</td>
<td>21.5</td>
</tr>
<tr>
<td>5</td>
<td>Paddy Husk</td>
<td>1.25</td>
<td>15.56</td>
<td>41.5</td>
</tr>
<tr>
<td>6</td>
<td>Ply Wood Waste</td>
<td>1.42</td>
<td>18.11</td>
<td>36.9</td>
</tr>
</tbody>
</table>

The average price of biomass fuel is around $41 - $43 per ton and the fuel cost escalates year by year. Higher fuel cost is a barrier to the existence of Biomass based power projects. Hence, optimal amount of fuel is to be used to reduce the cost incurred as well as maximum power output from the plant. Two cases of feedstock optimization is carried: first case with the objective of cost minimization alone and the second case with that of cost minimization and power output maximization dealt in the following sections:

**Single Objective Optimization of biomass feedstock using neural network**

Using the data provided by AMBEML as depicted in Table 3.1, optimization of the feedstock consumption is performed to minimize the cost using the neural fitting tool of the Artificial Neural Network (ANN) toolbox in Matlab 2010a. The nftool is a graphical user interface and is used to fit the practical biomass feedstock data. First, the data consisting of 6 input vectors for
the biomass fuel types and one target vector for the gross electricity generation are loaded. A feed-forward network is created (Mathworks-Fit Data with a Neural Network 2013) with default tan-sigmoid transfer function in the hidden layer and linear transfer function in the output layer. 20 neurons are used in one hidden layer. The network has six input neurons and one output neuron, because only one target value is associated with the input vectors. The network is trained with 18 data set of Biomass fuel consumed and it uses the default Levenberg-Marquardt algorithm for training. The application divides input vectors and target vectors into three sets as follows: 60% are used for training, 20% are used to validate that the network is generalizing and to stop training before over fitting and the last 20% are used as a completely independent test of network generalization. The method of data preprocessing is normalization and the mean square error has been found to be 0.0486.

**Multi-objective optimization of biomass feedstock using GA**

Optimal amount of fuel has to be used so as to minimize the cost as well as maximize the power output from the plant. Gimelli & Luongo et al (2012) have defined electrical efficiency of thermal power plant as the ratio of net power output and the product of mass flow of fuel and calorific value of the fuel. It implies that the net power output depends on the calorific value. But, greater quantity of fuel is to be utilized for maximum power output which will increase the cost further. A viable fuel mix with high calorific value and low processing cost has to be modeled to overcome this problem. Hence, a multi-objective problem is considered here which involves optimization of biomass fuels with the objectives of cost minimization and output power maximization. The objective function is to

Maximize:

\[ P_T = \sum H_{ij} \times X_{ij} \]  

and Minimize:
\[ Z_T = \sum C_{ij} \times X_{ij} \]  

(3.2)

Subject to:

\[ L_{X_{ij}} \leq X_{ij} \leq U_{X_{ij}} \]  

(3.3)

where, \( L_{X_{ij}} \) and \( U_{X_{ij}} \) are minimum and maximum quantity of biomass fuel available in the region; \( P_T \) is the total power generated for the all end uses for the operation of the system; \( H_{ij} \) is the heating value of the \( i^{th} \) fuel option for \( j^{th} \) end use (MJ/Kg); \( Z_T \) is the total cost of generation for the all end uses for the operation of the system; \( C_{ij} \) is the cost per unit of the \( i^{th} \) resource option for \( j^{th} \) end use ($/KWh); \( X_{ij} \) is the optimal amount of resource for \( j^{th} \) end use (KWh).

### 3.2.2 Sustainability Analysis

Sustainability is the overall capacity of the project to ensure continued functioning by considering the environmental, economic and social dimensions. The focus of this chapter is on the economic, financial and environmental aspects of sustainability.

#### 3.2.2.1 Techno-economic analysis of hybrid renewable energy system using HOMER

HOMER is an optimization tool for hybrid RE system developed by the U.S. National Renewable Energy Laboratory (NREL) and it helps to evaluate the techno-economic feasibility of a large number of technology options including both conventional and RE systems. It also accounts for variations in technology costs and energy resource availability. The feasibility analysis of the chosen solar-biomass hybrid system is performed for a textile industry and the results of the system configurations are analyzed in the subsequent sections.

Three scenarios are simulated and analyzed using HOMER software based on the consideration of all possible generation source options. The schematic diagram of the scenarios enumerating the system components for each
of the three cases is shown in Figure 3.5. The three scenarios analyzed for the economic feasibility are grid only, biomass only and solar-biomass hybrid system. In the first scenario, the demand of the industry is met with conventional grid system as in the case of many industries getting its supply from the state electricity board. Scenario-2 deals with the biomass only system. 4 MW Biomass generator has been modeled to supply the textile load and a Diesel Generator (DG) is used to meet the start-up load requirements of the biomass plant resulting in a mixed configuration.

![Scenario-1 Diagram](image1)

Scenario-1

![Scenario-2 Diagram](image2)

Scenario-2

![Scenario-3 Diagram](image3)

Scenario-3

**Figure 3.5 Schematic diagram of the scenarios analyzed**

Scenario-3 is the grid connected solar-biomass hybrid configuration with maximum RE penetration. Since there is enough potential for biomass and
solar power in the chosen area and subsidies are being provided by the Government for promoting such renewable sources, standalone biomass-solar hybrid system has been selected for meeting the demand of textile mill. As biomass has been considered as the prominent generating source, solar-PV system is used only to provide lighting load during the day time. Approximate lighting load of the yarn mill is around 100 KW and hence, the rating of the PV system is chosen as 100 KW.

3.2.2.2 CDM for Environmental Sustainability

Environmental sustainability is related to energy, resources and emissions savings. CDM can be considered as an important mechanism for sustainable development in developing countries. The prime aim of the CDM is to reduce pollutants cost effectively. As an indicator of environmental sustainability, it estimates the degree to which pollutants savings can be achieved through bio-energy use in the power sectors. In spite of the barriers in implementation of such renewable generation systems, maximum utilization of available RE sources can be achieved rapidly with the adoption of CDM in small scale project activities (Purohit et al 2009). Data obtained from AMBEMEL have been used for the theoretical estimation of Certified Emission Reduction (CER) potential for the textile industry.

As per Appendix B of simplified modalities and procedures for small scale CDM project activities (CDM: Recommendation Form for Small Scale Methodologies Version 01), biomass project activity falls under Type ID for thermal energy users. For Renewable energy technologies that displace electricity the simplified baseline is the electricity consumption times the relevant emission factor calculated as described in category ID, paragraphs 6 and 7 for the use of electrical energy only. As per the 2006 Intergovernmental Panel on Climate Change (IPCC) guidelines (2006), the baseline emission calculations are calculated as follows:
Baseline emissions = Net Electricity imported from the grid x Baseline Emission Factor

\[ BE = EG_{Grid} \times EF \]  

(3.4)

where, \( EG_{Grid} \) = The net electricity supplied to the grid by the plant during the year y

\( EF \) = The baseline emission factor for the electricity displaced due to the project activity in tons CO\(_2\)/MWh.

But, \( EG_{Grid} = \text{Min} \ (EG_{Fossil}, EG_{Biomass}) \)  

(3.5)

(i) Calculation of \( EG_{Fossil} \)

\[ EG_{Fossil} = EG_{Export} - EG_{Import} \]  

(3.6)

where,
\( EG_{Fossil} \) = The net electricity supplied to the grid adjusted for fossil usage during the year (MWh).
\( EG_{Export} \) = The total electricity being exported by the project activity during the year (MWh).
\( EG_{Import} \) = The total electricity being imported by the project activity during the year (MWh).

(ii) Calculation of \( EG_{Biomass} \)

\[ EG_{Biomass} = EG_{Biomass\ fu} - EG_{aux} \]  

(3.7)

where,
\( EG_{Biomass\ fu} \) = The estimated gross electricity generation by biomass firing in the project activity during the year (MWh).
\[ EG_{aux} = \text{The auxiliary consumption attributable to the project activity during the year (MWh)} \]

\[ EG_{biomassfuels} = \frac{FC_{jf}}{SFC_{jf}} + \frac{FC_{Gs}}{SFC_{Gs}} + \frac{FC_{Bag}}{SFC_{Bag}} + \frac{FC_{Cf}}{SFC_{Cf}} + \frac{FC_{Ph}}{SFC_{Ph}} + \frac{FC_{Ply}}{SFC_{Ply}} \] \quad (3.8)

where,

\[ FC_{jf} = \text{Quantity of Juliflora consumed in the project activity during the year (tons)} \]

\[ SFC_{jf} = \text{Specific fuel consumption of Juliflora in AMBEM during the year (tons/MWh)} \]

\[ FC_{Gs} = \text{Quantity of Groundnut Shell consumed during the year (tons)} \]

\[ SFC_{Gs} = \text{Specific fuel consumption of Groundnut Shell consumed during the year (tons/MWh)} \]

\[ FC_{Bag} = \text{Quantity of Bagasse consumed during the year (tons)} \]

\[ SFC_{Bag} = \text{Specific fuel consumption of Bagasse consumed during the year (tons/MWh)} \]

\[ FC_{Cf} = \text{Quantity of Coconut Fibre consumed in the project activity during the year (tons)} \]

\[ SFC_{Cf} = \text{Specific fuel consumption of Coconut Fibre consumed during the year (tons/MWh)} \]

\[ FC_{Ph} = \text{Quantity of Paddy Husk consumed in the project activity during the year (tons)} \]

\[ SFC_{Ph} = \text{Specific fuel consumption of Paddy Husk consumed during the year (tons/MWh)} \]

\[ FC_{Ply} = \text{Quantity of Plywood Waste consumed during the year (tons)} \]

\[ SFC_{Ply} = \text{Specific fuel consumption of Plywood Waste consumed during the year (tons/MWh)} \]
The amount of electricity generated using biomass fuels is compared with the amount of electricity generated using specific energy consumption and amount of each type of biomass fuel used. The minimum of the two values is used to calculate emission reductions.

### 3.2.2.3 Financial analysis of solar-biomass hybrid system

Economic growth is the main reason for the implementation of any project activity. From an internal point of view, microeconomic sustainability presents the project’s capability to manage resources and maintain long-term profitability. The monetary benefits of biomass – solar hybrid system are assessed by calculating various costs like installation cost, cost of fuel and maintenance cost for the chosen system. Cost Of Energy (COE), Internal Rate of Return (IRR) and payback period are found to be the appropriate financial indicators of sustainability analysis and they are computed for the proposed hybrid system. As the rating of PV system is chosen smaller, IRR and payback period are calculated for Biomass system only.

(i) Cost of Energy

Cost of Energy is the most comprehensive measure of power generation system. This measure incorporates all the elements of cost, i.e. installed capital cost, cost of maintenance, cost of major overhauls and fuel. It is the ratio of the total cost incurred by the power system to the total energy generated per year.

(ii) Internal Rate of Return

To ascertain the suitability of the biomass system for textile industry, payback and Internal Rate of Return (IRR) need to be calculated. Internal Rate of Return, an economic indicator of economic viability of a firm in the long run, has been attempted in the present study for the proposed captive biomass plant in
the textile mill chosen for the study. The assumptions made keeping in mind various parameters are as follows

1. The period of rate of return from the plant is assumed to be ten years
2. The unit rate of 0.048 $ is assumed to persist for ten years
3. The net power generated @ 0.048 $ per unit is assumed to be the revenue for textile mill for the calculation purpose, though it is to be used for running the textile unit
4. The salaries and Admin expenses, O & M, Fuel cost is assumed to increase by 5 % per annum

Keeping the above assumptions in mind, the calculation of IRR has been carried out as given in Appendix. The revenue for the biomass plant is calculated by multiplying the net units generated and tariff rate as seen in Table A3.1 (a). Gross profit is obtained by subtracting sub-total in Table A3.1 (b) from the revenue.

IRR is defined as the discount rate at which the investment makes more money than its actual cost. Based on this, the internal rate of return formula can be formulated as

\[ CF_0 + \frac{CF_1}{(1+r)^1} + \frac{CF_2}{(1+r)^2} + \frac{CF_3}{(1+r)^3} + \ldots \ldots + \frac{CF_n}{(1+r)^n} = 0 \]  \hspace{1cm} (3.9)

where, CF represents the cash flow generated in each time period; n represents the last time period and r represents the IRR value.

(iii) Simple Payback period

Payback period is given by the ratio of Investment cost of the system to the Net Cash flows due to the adoption of the system. The value of net cash flows is the value for the first year in Table 3.1 (c). In practical cases, the value may vary due to variation in net cash flow.
3.3 RESULTS AND DISCUSSION

The results of the fuel viability, economic feasibility and environmental sustainability analysis are presented and discussed in the subsequent sub-sections.

3.3.1 Results of Fuel Mix Optimization

Single Objective optimization

The performance plot of biomass fuel mix optimization using ANN is shown in the Figure 3.6. The network is trained with 18 data set of Biomass fuel consumed and the optimized results for the 4 MW power generation have been obtained as displayed in Figure 3.7. The input to the neural network is the biomass power generation and the output is the optimal fuel feed which is the combination of six fuel types. The optimized value of the 6 fuel types is found to be a total of 6951 tons which has been utilized for the economic evaluation of the hybrid system dealt in the succeeding section. The optimized fuel feed is found to be very close to the quantity used by the plant operator as suggested by the management of AMBEML.

Figure 3.6 Performance plot of ANN optimization
Multi-objective optimization

The multi-objective Genetic Algorithm (GA) function ‘gamultiobj’ of Matlab uses a controlled elitist GA, a variant of NSGA-II (Deb 2001). Controlled elitist GAs favour individuals that can help increase the diversity of the population even if they have a lower fitness value. The initial population is generated randomly by default. The next generation of the population is computed using the non-dominated rank and a distance measure of the individuals in the current generation. The algorithm of NSGA-II is presented as a flowchart in Figure 3.8. The program is written and run with global optimization toolbox of Matlab 2011a.
The GA toolbox in MATLAB is used for optimization using the ‘gamultiobj’ function to identify the set of non-dominated solutions. The simulation was run in Matlab 2011a with the following parameters: population size is 200, the algorithm is stopped at maximum generation of 10000 and selection is by tournament. The limits of the fuel availability constraint are
\[300 \leq x(1) \geq 6000; \]
\[0 \leq x(2) \geq 2500; \]
\[300 \leq x(3) \geq 5000; \]
\[30 \leq x(4) \geq 1000; \]
\[0 \leq x(5) \geq 350; \]
\[65 \leq x(6) \geq 3200; \]

where, \( x(1), x(2) \ldots x(6) \) are the availability of the 6 fuel types which is calculated based on the actual consumption of the fuels in AMBEML. In order to enhance the future sustainability of biomass resources, optimization of biomass feedstock combination is performed based on the procurement cost of biomass and heating value of the type of biomass feedstock used and the availability of the fuel in tons. The biomass fuel consumption data for the year 2012 has been provided by AMBEML as depicted in Table 3.1, based on which the fuel availability values in tons are calculated for the optimization. The heating value, costs of biomass fuel per ton considered for optimization are obtained from AMBEML as seen in Table 3.2.

![Figure 3.9 Pareto frontier and score histogram of the optimization](image-url)
The pareto front and score histogram are shown in Figure 3.9. In multi-objective optimization and pareto solution, each point can be used as an optimized point. Hence, optimal solution is dependent on the criteria of the decision maker. With the vector of feasible solution offering several tradeoffs, the most beneficial solution is obtained by fuzzy pareto dominance (Abido et al 2003).

To observe the variation in the characteristics of the two objective functions, three points A,B,C have been considered in the pareto front of Figure 3.9. Point A is preferred when objective of cost has more weightage and Point B is preferred when calorific value has more weightage. Out of the 70 feasible solutions in the pareto front, point C is the compromised solution as per the fuzzy pareto dominance approach and given in Table 3.3. The minimized fuel cost $Z_T$ obtained from optimization is 41000 $. The minimized calorific value is $4.3 \times 10^{-8}$ which is converted into maximum value by taking the inverse of the obtained value as seen in column $P_T$ of Table 3.3. The values of $x_2$ and $x_5$ are very low as these biomass fuels are available only during season and the tool takes up the lower limit of the fuel availability constraint.

<table>
<thead>
<tr>
<th>Points</th>
<th>$Z_T$ ($\text{$}$)</th>
<th>$P_T$ (MJ/Kg)</th>
<th>$x_1$ (tons)</th>
<th>$x_2$ (tons)</th>
<th>$x_3$ (tons)</th>
<th>$x_4$ (tons)</th>
<th>$x_5$ (tons)</th>
<th>$x_6$ (tons)</th>
</tr>
</thead>
<tbody>
<tr>
<td>A</td>
<td>2.3E+04</td>
<td>1.2E+07</td>
<td>300</td>
<td>0.004</td>
<td>300</td>
<td>30</td>
<td>0.016</td>
<td>65</td>
</tr>
<tr>
<td>B</td>
<td>9.6E+04</td>
<td>5.9E+07</td>
<td>5056</td>
<td>8.21</td>
<td>3268</td>
<td>715</td>
<td>4.857</td>
<td>2867</td>
</tr>
<tr>
<td>C</td>
<td>4.1E+05</td>
<td>2.3E+07</td>
<td>622</td>
<td>2.41</td>
<td>556</td>
<td>138</td>
<td>2.709</td>
<td>227</td>
</tr>
</tbody>
</table>

With the compromised solution of maximum power output and minimum cost obtained from the optimization, extra biomass resource utilization is avoided and thereby conservation of the energy is obtained.
3.3.2 Results of the Techno-economic Analysis

The results of the three scenarios analyzed are compared in terms of economic and environmental aspects. The cost and emission results are compared for the three scenarios in Table 3.4. In the ‘grid only’ scenario, the system produces 17,700 MWh yr\(^{-1}\) of electricity with a net present cost of 19 M$. But pollutants are the highest about 15,050 tons/year, which is due to fossil fuel based generation. The aim of the second scenario is to meet the electricity demand of the textile industry by ‘biomass only’ system. The start-up load requirements of the boiler are to be met with the diesel generator. This mixed configuration produces 21,414 MWh/yr (99%) of the total electricity, with biomass fuel consumption of 56,666 tons/ year. The Net Present Cost (NPC) is about 37 $ and the Levelized Cost Of Energy (LCOE) is 0.137$ / KWh. Scenario-3 is the grid connected PV-biomass hybrid configuration which produces 21,290 MWh/yr about 99% of the total electricity required, with biomass fuel consumption of 56,854 tons/ year and 143,681 kWh yr\(^{-1}\) of the total electricity with Solar. The Net Present Cost (NPC) is 35.8 M$ and the LCOE is 0.131 $ / KWh as seen in Table 3.4.

Table 3.4 Cost and emission results

<table>
<thead>
<tr>
<th>Parameters (Units)</th>
<th>Economic parameters and Emissions</th>
<th>Scenario 1</th>
<th>Scenario 2</th>
<th>Scenario 3</th>
</tr>
</thead>
<tbody>
<tr>
<td>NPC($)</td>
<td></td>
<td>18,556,392</td>
<td>37,415,384</td>
<td>35,843,284</td>
</tr>
<tr>
<td>LCOE ($/KW-hr)</td>
<td></td>
<td>0.082</td>
<td>0.137</td>
<td>0.131</td>
</tr>
<tr>
<td>Operating Cost ($/year)</td>
<td></td>
<td>1,451,606</td>
<td>2,550,729</td>
<td>2,459,705</td>
</tr>
<tr>
<td>Pollutants</td>
<td></td>
<td>15,047,128</td>
<td>103,434</td>
<td>5,465,770</td>
</tr>
</tbody>
</table>

On comparing the three cases, it can be seen that the NPC of the hybrid system is higher than the Grid only system due to the high feedstock rate of Biomass system and investment involved in PV-Biomass system. The
advantage of PV-Biomass hybrid system in this context is that in Biomass only system, the diesel generator has to cater low loads for several hours which ends up in degradation. The hybridization of the PV system with Biomass reduces the fuel consumption and improves the performance and operational life of the diesel generator. The grid connected PV-biomass hybrid system is the appropriate choice with regard to maximum utilization of the available renewable resources and uninterrupted power supply to the textile industry. The operating cost of the hybrid system is also 2.5 M$ lower than that of biomass generation system which is 2.6 M $.

The comparison of costs and emissions of the three scenarios as in table justifies biomass - solar hybrid system to be the most sustainable energy option for the textile industry. With the advancement in technology, the price of the system components will be reduced and renewables will become the trend of the future.

3.3.3 Results of the Environmental Analysis

The purpose of implementing the proposed standalone hybrid RE system is to effectively utilize the available renewable sources in generating electrical energy for the textile industry and be self-reliant in achieving the energy demand. In view of the power shortage situation of the state, the proposed work will demonstrate the concept of decentralized electricity using renewables and benefits of carbon abatement by implementing this project under the Clean Development Mechanism (CDM) of United Nations Framework Convention for Climate Change (UNFCCC). As per the IPCC guidelines for the estimation of baseline emissions presented in section 3.2.2.2, the net electricity consumed by the textile mill from the grid is calculated as $E_{G_{Fossil}} = 17,885 \text{ MWh}$. The estimated gross electricity generation by firing the biomass fuels is calculated using the SFC values and quantity of fuel consumed during the year 2012.
\[ EG_{\text{Biomassfuel}} = 107,385 \text{ MWh} \text{ (data obtained from AMBEML)} \]

As per the equation (2), \( EG_{\text{Grid}} = \text{Min} (EG_{\text{Fossil}} \cdot EG_{\text{Biomass}}) \Rightarrow EG_{\text{Grid}} = EG_{\text{Fossil}} \)

Therefore, \( EG_{\text{Grid}} = 17,885 \text{ MWh} \)

The Grid emission factor for southern grid in tons of CO\(_2\) per MWh is 0.85.

i.e., \( EF = 0.85 \text{ tCO}_2/\text{MWh} \)

Hence, Baseline Emissions as per the equation (1),
\[ BE = 17,885 \text{ MWh} \times 0.85 \text{ tCO}_2/\text{MWh} = 15,202.25 \text{ tCO}_2 \]

The Project emission due to the transportation of biomass and usage of diesel generator is found to be 815.95 tCO\(_2\) as per the data provided by AMBEML. The estimated amount of pollutants due to power generated from the biomass power plant is 15,202.25 – 815.95 = 14,386 tCO\(_2\). If the project is assumed to be credited for 10 years, the total estimated pollutant reductions are found to be 143900 tCO\(_2\). The total estimated emission savings from the implementation of the biomass project activity is assumed to be proportional to the scale of electrical production and hence contributes to the environmental sustainability of the biomass based power plants.

Certified Emission Reduction (CER) is a measure of sustainable development through CDM project and it leads to global sustainability. This indicator is represented as emissions reduced through project activity. The amount of GHG emission reductions by implementation of solar-biomass hybrid system under CDM for the textile mill is estimated for a year and the carbon credits are computed by multiplying the total carbon saved in tons due to the hybrid system and market price per ton in dollars. The CERs for the biomass-solar hybrid system is depicted in Table 3.5.
Table 3.5 Certified emission reductions for the Biomass-solar hybrid system

<table>
<thead>
<tr>
<th>Description</th>
<th>Units</th>
</tr>
</thead>
<tbody>
<tr>
<td>Carbon saved per KWh from Biomass power</td>
<td>0.85 Kg</td>
</tr>
<tr>
<td>Estimated Net generation</td>
<td>21,200 MWh from Biomass + 143.68 MWh from Solar</td>
</tr>
<tr>
<td>Carbon saved from Biomass power</td>
<td>18,020 tons</td>
</tr>
<tr>
<td>Carbon saved per KWh from Solar generation</td>
<td>0.106 Kg</td>
</tr>
<tr>
<td>Carbon saved from Solar power</td>
<td>15 tons</td>
</tr>
<tr>
<td>Total CERs for hybrid system</td>
<td>18,035</td>
</tr>
<tr>
<td>Market price per ton in Dollars</td>
<td>16.8 $</td>
</tr>
<tr>
<td>Total earnings in Rupees</td>
<td>0.30 million dollars</td>
</tr>
</tbody>
</table>

If the plant is a Clean Development Mechanism (CDM) registered project activity, it can be seen from the table that the total credits for the power producer from the carbon saved is about 0.30 million dollars. The carbon credits that would be obtained is an added revenue to the industry utilizing renewable energy sources. The above CERs calculation can be extended for any rating of the hybrid system for electrification of the industries as well as decentralized rural electrification.

3.3.4 Results of the Financial Analysis

In this paper, the economic sustainability has been analysed through the financial performance of the project activity and its capability to manage assets. The financial indicators like COE, IRR and payback period are computed and the results are discussed in this section,

The Cost Of Energy (COE) of the hybrid system is a comprehensive measure of economic sustainability and is calculated as follows: 4 MW Biomass generator and 100 KW PV system has been considered here. The cost of 100 KW Solar PV-battery power system including the subsidy of 30% for solar panels from the Ministry for New and Renewable Energy (MNRE) is around 0.2
The computation of per unit cost for solar-biomass hybrid system is shown in Table 3.6. The number of units generated per day by the PV system is calculated by multiplying sunshine hours with 70% of the PV system rating (100 KW) chosen. The maintenance cost of the solar PV plant is 1% of the installation cost and that of biomass plant is 5% of the installation cost. Biomass Fuel required for 4 MW plant is about 6266 tons and the average cost of Biomass fuel is 43 $ per ton.

From the table, the calculated per unit generation cost is 0.04 $ with the proposed hybrid energy system whereas the tariff for industries is 0.085 $ with the conventional grid supply. As, the hybrid energy system doesn’t involve operating costs and labour cost, the generation cost of biomass based RE system is less than that of conventional energy system. As Biomass plant load factor is about 85%, majority of the load demand of the textile mill is met with biomass system and only lighting load is met with PV system. At present, the MNRE has extended 2% subsidy towards the capital cost of Biomass power plant. This subsidy regime is expected to increase in ensuing years due to the importance given to the renewable sources. Hence, if the subsidy assumed to be increased from 2% to 30%, there will be a reduction in COE for the hybrid system and the hybrid system is affordable for industries with potential resource availability.

Table 3.6 Computation of per unit cost of the hybrid system

<table>
<thead>
<tr>
<th>Description (unit)</th>
<th>PV system</th>
<th>Biomass system</th>
</tr>
</thead>
<tbody>
<tr>
<td>Installation cost (million $)</td>
<td>0.2</td>
<td>3.7</td>
</tr>
<tr>
<td>Maintenance cost ($)</td>
<td>2,055</td>
<td>73,846</td>
</tr>
<tr>
<td>Fuel purchase cost ($)</td>
<td>-</td>
<td>3.5</td>
</tr>
<tr>
<td>Sunshine hours</td>
<td>7</td>
<td>-</td>
</tr>
<tr>
<td>Operating years</td>
<td>20</td>
<td>20</td>
</tr>
<tr>
<td>Total cost (million $)</td>
<td>0.2</td>
<td>7.2</td>
</tr>
<tr>
<td>Generated units per day</td>
<td>490</td>
<td>49,000</td>
</tr>
<tr>
<td>Per unit cost($)</td>
<td>0.06</td>
<td>0.02</td>
</tr>
<tr>
<td>Per unit cost of the hybrid system ($)</td>
<td>0.04</td>
<td></td>
</tr>
</tbody>
</table>
Another metric of interest in the financial analysis is the IRR. IRR is a measure of the profitability of the investment made. The calculation of IRR without including CDM revenue is given in Table A3.1(c). The value of IRR (8%) is less than the weighted average of the project cost (13%). The inclusion of CDM revenue of 0.30 million dollars can improve the project viability by increasing the IRR value by 2%, which ascertains the profitability of the biomass system in the internal point of view of the investors.

Payback period is also an indicator to demonstrate the sustainability of the present biomass-based business. If this value is not within the project’s lifetime, the investors will eventually pull out of the biomass business. Payback period for the biomass plant = 4078949 $ / 624805 $ = 6.5 years.

In practical cases, the value may vary due to variation in net cash flows. Since the payback period is less than the lifetime of the project, the proposed hybrid system is suitable for industries in agriculture prone areas.

The financial indicators analyzed demonstrate the economic viability of the biomass based hybrid system for the textile industries. Hence, the hybrid system is appropriate and affordable for industries with potential resource availability.

Overall, the biomass based hybrid system will contribute to sustainable development in the following ways:

- Due to the proposed project, fossil-fuel based power generation will be replaced with a clean and sustainable renewable source of energy.
- The project will set a pilot example for using biomass waste resources for independent power generation in India and will improve the availability of electricity in the grid. Thus it helps to secure the future energy supply for the Indian economy.
The project will create job opportunities with regard to construction works and plant operation in the rural area.

Hence, the proposed hybrid system will have a very positive sustainable development impact due to its pilot initiative by using a clean energy source for independent power generation.

3.4 POST SUSTAINABILITY ANALYSIS

Transition from conventional energy system to renewable energy based system will have certain economic impacts. Although a high share of renewable energy will be more cost effective than fossil fuels over the entire lifecycle of new power installations, the relatively high investment costs for renewables remains an important challenge. Further improvements in the financial sector will thus be necessary to make use of full renewable energy potential of the region. These include optimal exploitation of the locally available resources and financial guarantees to improve investment security in the sustainable energy market. The following section analyze the barriers for the proposed biomass based supply system and provides possible solutions to overcome the barriers in implementing such RE system. The key challenge for biomass based power generation is to ensure right kind, right quality, right quantity and right channel of procurement of biomass available within a certain distance from the plant. Each of the above is essential for effective and economic operation of biomass based plants.

The right kind is the type of technology that has to be chosen appropriate for the different types of biomass available in the locality. Biomass gasifier technology is often adopted for small scale decentralized projects like rural electrification. Large scale biomass projects face problems in their successful operation due to the shortage in biomass resources, increased fuel cost and lack of incentives from the Government. Now, MNRE promotes gasifier and
Boiler-Turbine–Generator (BTG) based biomass power generation for off-grid applications upto few MW scale. As a medium scale project requiring 4 MW, the textile industry can adopt BTG technology for its efficient operation. At the end of the project’s life time of 20 years, Concentrated Solar Power (CSP) technology can replace the bio-energy unit with slight modifications.

The right quality is the one that has high calorific value that is necessary to increase the efficiency of these plants. Biomass fuels of high calorific value, gives maximum power output at higher purchase cost. The right quantity of fuel has to be fed into the boiler to match the power requirement of the textile unit. The increasing cost of fuel is a barrier to the biomass power generation. The average price of biomass fuel is around $ 41 - $ 43 per ton in the present scenario and the fuel cost escalates by 5% year after year. The solution will be to plant dedicated crops in the waste lands of the textile industry and also involve the farmers in ‘contract farming’ in waste lands of the industrial location to ensure biomass fuel availability throughout the year.

The right channel of procurement of biomass and accessing International Sustainable Energy Finance are essential to reduce the cost of running the biomass based power plants. High interest rates and the lack of long-term loans pose a major barrier for financing sustainable energy projects. The subsidies from MNRE are geared mostly toward smaller scale energy investments, and for the most part would not be sufficient for utility-scale renewable energy investments. Additional sources of financing are required for these projects. International financing for CDM projects has and will continue to play a key role in funding sustainable energy projects in India.

The carbon credits can be obtained by registering the project activity under CDM which would lower the investment burden of the industry. However, biomass tariff policy and lack of regulatory framework can obstruct the project development. This is the prevailing issue of concern towards the implementation
of such off-grid renewable energy projects. Therefore, incentives and information policies of the Government should be regulated to achieve long term sustainability.

3.5 CONCLUSION

This work aims at the sustainable development through techno-economic feasibility analysis of PV/Biomass hybrid system for textile industry in the chosen region of T.Kallupatti in Madurai district and environmental viability through CDM. The long term sustainability of Solar-Biomass Hybrid Power Generation is ascertained by performing post-sustainability analysis. The decisions drawn based on the computation and simulation results are:

- Pollutants are the least with biomass only and biomass based hybrid RE system compared to that of grid only system.
- Biomass is the promising and sustainable option for industries located in areas where intensive agriculture is practiced in India and the generation cost is found to be relatively lesser than the conventional energy system.
- Carbon credits that can be obtained by the industrial project registered under CDM is 0.30 M$ which can be an added revenue to the industry of the chosen region contributing towards sustainable development.

In spite of the barriers in implementation of the biomass cogeneration plant, the success of this CDM project will prompt for replication not only in other textile units, but in all industrial sectors wherever there is a possibility of implementing biomass based captive cogeneration and aids to further pollutants to the atmosphere. The economic analysis show that the conventional grid system costs less than the cost of the hybrid biomass-solar system in the present scenario. In future, with successful technological up gradation, the price of PV system will drop and it will be the best renewable option for power generation in
India. With increasing diesel price, specific power requirement year over year and uncertain grid power availability, the proposed hybrid Solar-Biomass power system may be the inevitable generation option for any industry with enough biomass and solar resource availability. The proposed system may also be appropriate for decentralized rural electrification as small scale power plants result in the reduction of overall cost as well as transmission losses. This biomass based hybrid system proves to be a possible path for agriculturally rich areas in terms of socio-economic and environmental sustainability. But this can be achieved depending on the investment capacity of the industry, incentives and information policies of the Government.