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An economic and environmental analysis of biomass-solar hybrid system for the textile industry in India

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Abstract: This paper focuses on the design and analysis of a hybrid biomass-solar photovoltaic system for the textile industry with the goal of minimizing the cost and greenhouse gas emissions. The feasibility analysis of the hybrid system is performed based on the resource availability and the power generation potential of the existing biomass power plant near the textile plant at T.Kallupatti in Tamil Nadu, India. The power plant located at the site (9.66°N, 77.79°E) has an average daily global horizontal irradiance of 4.86 kWh/m^2, which has been validated through NASA Surface Meteorology and Solar Energy data. The chosen site also has adequate biomass fuel availability. The biomass feedstock fuel price varies from $38.5 to $42 per ton on average for the fuels juliflora, bagasse, coconut shell, paddy husk, etc., which are purchased from nearby villages of the chosen region. The comparative analysis of grid-alone, standalone biomass-solar hybrid, and grid connected biomass-solar hybrid systems is performed using HOMER 2.81 software. In particular, an economic and environmental evaluation of the hybrid system is carried out based on the results of the optimization of biomass feedstock combination for maximum power output using the Neural Network toolbox of MATLAB 2010a. The results prove the effectiveness of the stand-alone solar-biomass hybrid system for the textile industry in terms of cost combined with emission reductions.

Key words: Biomass-solar hybrid system, HOMER simulation, biomass feedstock optimization, economic evaluation, carbon credit

1. Introduction

The day-by-day increasing energy consumption and the decreasing accessibility of conventional energy sources have led to a hike in the price of electricity. Hence, the principal aim of most of the countries in the world is to provide a reliable, cost-effective, environmentally friendly and affordable supply of electrical energy. Renewable energy (RE) sources like wind, solar, biomass, and fuel cells have been getting more prominent attention in the recent years. In India, solar, wind, and biomass are the most preferred renewable energy sources, particularly in Tamil Nadu, because of the availability of enormous resources [1,2]. Tamil Nadu has reasonably high solar insolation (5.6–6.0 kWh/m^2) with around 300 clear sunny days in a year and has also announced its State Solar Energy Policy with a target of 3000 MW up to year 2015 with the addition of 1000 MW capacity each year starting from 2013. The current availability of biomass of India is estimated to be 500×10^6 t per year. In Tamil Nadu, the estimated power generation potential from surplus biomass is 487 MW according to a district-level study carried out by Anna University and the Ministry of New and Renewable Energy Funding. There

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are 17 biomass power plants in the state, each with a capacity of 7–10 MW. Nearly 130 MW is contributed by independent biomass generators.

The average daily electricity requirement of Tamil Nadu is about 12,500 MW and the overall generation has reached a maximum of 11,500 MW due to the establishment of additional units of thermal plants and wind power plants. Still there exists an appreciable gap between generation and demand. Moreover frequent and unannounced power cuts affect the public and also industries in terms of turnovers. With the escalating cost of fuel prices and power shortages, industries are setting up their own captive power plants based on the availability of coal, diesel, or other fuels in that location. The Government of India has made it mandatory under the Electricity Act of 2003 to use 25% of power from RE sources. As the government is providing incentives for RE generation, industries are obliged to utilize those resources [3] and reduce greenhouse gas emissions as prescribed under the charter of the Corporate Responsibility for Environmental Protection.

For the past few years, much research has been conducted regarding standalone and grid-connected RE sources all over the world. The HOMER tool has been used to analyze a hybrid electric supply system (hydro/PV/wind) and to find the optimum sizing of components for a diesel-based RE system [4,5]. Feasibility studies have been performed to foresee the suitability and cost-effective application of hybrid RE systems with energy storage technologies for a particular locality/region [6–8]. In India, biomass-based hybrid energy systems have been analyzed to offer a more financially viable solution for rural areas [9,10] and the environmental impacts of the introduction of a biomass-based energy system have also been discussed [11]. Most of the literature concentrates on the electrification of households and rural areas, but industrial units have not been considered to cater to the socioeconomic development of the whole region. The carbon credits obtained by such RE systems are also not focused on. These factors are taken into account in the present study to bridge this gap.

The objective of this paper is to analyze the feasibility of using a biomass-solar hybrid system for a textile plant located 5 km away from the existing biomass project activity using the HOMER software tool. An economic evaluation of the solar-biomass hybrid system is performed based on the results of the biomass feedstock optimization using the Neural Network toolbox of MATLAB 2010a. The simulation results, economics of changeover to the hybrid system, and computation of carbon credit are presented in the subsequent sections.

2. Feasibility analysis of biomass-solar hybrid system

2.1. Overview of Auro Mira Bio Energy Madurai Limited

Auro Mira Bio Energy Madurai Limited (AMBEML) has implemented a 10 MW biomass power plant at the village of T.Kallupatti in Madurai district of Tamil Nadu. The front view of the grid-connected plant is shown in Figure 1. The site measurement is about 27 ha and the road from the site connects to T.Kallupatti in 8 km and Madurai railway station and Madurai airport in 40 km. The plant started its commercial operation on 5 May 2009. It is located on the highway from Madurai (via T.Kallupatti) to the Rajapalayam road as seen from the location map in Figure 2.

The biomass fuels used for the power generation are juliflora, bagasse, ground nut shell, paddy husk, plywood waste, and coconut fiber. In the absence of project activity, an equivalent amount of electricity would have been generated by the conventional power plants connected to the southern grid. These conventional power plants are based on fossil fuels and are more carbon-intensive. The project activity employs Rankine cycle technology for the power generation process. The technology involves direct combustion of biomass that takes place through a multifuel-fired boiler to generate a high-pressure and high-temperature steam. The details of the major equipment installed at AMBEML are listed in Table 1.

Figure 1. Front view of the grid connected biomass plant.

Figure 2. Location map of AMBEML.

Table 1. Equipment details of AMBEML.

S. no.	Equipment	Specification
1.	Boiler	46 TPH, travelling grate, 66 kg/cm^2, 495 °C
2.	Turbine generator	10 MW condensing-cum-single extraction type 11 kV synchronous generator
3.	Air-cooled condenser	Input - 46 TPH, no. of shells- 3 Type of cooling - motor-driven air fan cooling Type of heat exchanger – finned tube heat exchanger
4.	Fuel handling system	40 TPH - belt conveyor - 1 40 TPH - slat chain conveyor - 1
5.	Weigh bridge	TM 950 - capacity 40 t
6.	Diesel generator	Voltage - 415 V, current - 695.6 A, rating - 500 kVA, 400 kW

2.2. Availability of renewable resources

2.2.1. Potential of solar energy at AMBEML

The solar radiation data for AMBEML at T.Kallupatti of the Madurai district were obtained from the NASA Surface Meteorology and Solar Energy website (https://eosweb.larc.nasa.gov.cgi-bin/sse/grid.cgi) as seen in Table 2. It is obvious that the average daily global horizontal irradiance is 4.86 kWh/m^2. This means that there is enough solar potential and a considerable amount of solar energy can be obtained throughout the year. The monthly insolation data are fed as solar resource inputs into the HOMER tool for the feasibility study of the biomass plant at the chosen site.

Table 2. Monthly averaged insolation incident on a horizontal surface.

Lat. 9.66; long. 77.7	22-year average (kWh m^{-2} day^{-1})
January	4.95
February	5.73
March	6.27
April	5.53
May	5.23
June	4.26
July	4.19
August	4.48
September	4.92
October	4.30
November	4.15
December	4.41
Average	4.86

2.2.2. Potential of biomass resources

Agriculture is the prime occupation of the people living in T.Kallupatti. In this region, cotton is the major crop due to the presence of typical block cotton soil. Rice is also being cultivated in the region extensively, followed by groundnut cultivation. Juliflora, bagasse, ground nut shell, paddy husk, plywood waste, and coconut fiber are the fuels purchased at an average of $38.5–$42 per ton by AMBEML. The data of monthly average biomass feedstock consumption by the plant and electricity supplied to the grid in 2012 obtained from AMBEML are shown in Table 3. The net annual electricity supplied to the grid is calculated to be 51,800.5 MWh.

2.3. Load profile of textile industry

The textile industry plays a significant role in the Indian economy by providing direct employment to an estimated 35 million people, thereby contributing 4% of GDP and 35% of gross export earnings. The textile sector contributes 14% of the manufacturing sector. Tamil Nadu is among the largest garment exporters in India and sometimes it is referred to as the textile valley of India. Due to the unscheduled power cuts in the state, textile factories face severe revenue loss. Hence, a textile mill has been chosen for the suitability analysis of the solar-biomass hybrid system. Vee Bee Yarn Textile Private Ltd. is a textile mill located 5 km from AMBEML, a few minutes' drive from the cultural capital of the state, Madurai. The mill was started with 14,000 spindles of capacity and has grown to produce 80,000 spindles with a total demand of 2200 kVA. It gets the required power from the Kunnathur Substation. The approximate load profile of the mill is given in Table

4. Using the data in the table, the average daily load is scaled to be 49 MWh with 4 MW peak and is used as load input in the HOMER tool.

Table 3. Electricity supplied to the grid.

S. no.	Month of the year, 2012	Electricity		Biomass Consumed (t)
		Export to the grid (MWh)	Import to the grid (MWh)	
1.	January	4584.6	0.5	9704.780
2.	February	3376.2	24	7200.185
3.	March	3738.3	23.4	7868.975
4.	April	5508	32.2	9390.055
5.	May	5301.5	16.5	10,044.330
6.	June	4631.1	50.4	8862.199
7.	July	4368.9	47.6	8102.053
8.	August	4694.3	37	7878.814
9.	September	3797.9	58.3	6771.784
10.	October	3647.5	36	5972.916
11.	November	3859.4	44.5	6177.795
12.	December	4680.5	17.3	8675.616

Table 4. Load profile of M/s. Vee Bee Yarn Textile Private Ltd.

S. no.	Processing unit	Power consumption (kW)	Load factor
1.	Blow room	200	0.6
2.	Preparatory unit	350	0.75
3.	Simplex	150	0.7
4.	Spinning	1580	0.8
5.	Cone winding	100	0.8
6.	Compressor	100	0.78
7.	Lighting	100	1

2.4. Optimal hybrid system modelling using HOMER

HOMER is an optimization tool for hybrid RE systems developed by the National Renewable Energy Laboratory of the United States, which provides optimized results of the hybrid system by performing thousands of simulations based on input parameters like solar irradiation, fuel price, renewable energy fraction, and cost of the proposed hybrid system. HOMER requires technical inputs like solar power, biomass resources, etc., and economic inputs of RE source components. The average biomass feedstock availability of AMBEML and the purchase price per ton of the feedstock during 2012 are entered as biomass resource inputs in HOMER, as seen in Figure 3. The model inputs and cost assumptions are listed in Table 5. Three scenarios, i.e. grid-only, standalone biomass-solar hybrid, and grid connected biomass-solar hybrid system, are simulated and analyzed using HOMER. The schematic diagram enumerating the system components for each of the three cases is shown in Figure 4.

2.5. Simulation and obtained results

2.5.1. Scenario 1: grid-only system

The grid-only system is the conventional electric power supply system for the textile mill. The system produces 17,702,504 kWh year^{-1} (100%) of the total electricity with a net present cost (NPC) of $18,556,392. However,

Table 5. Component costs of the hybrid system.

System (size)	Capital cost ($)	Replacement cost ($)	O & M cost
Photovoltaic (1 kW)	2000	2000	0 ($/year)
Biomass generator (1 MW)	1,000,000	850,000	0.010 ($/h)
Diesel generator (1 kW)	500	500	0.25 ($/h)

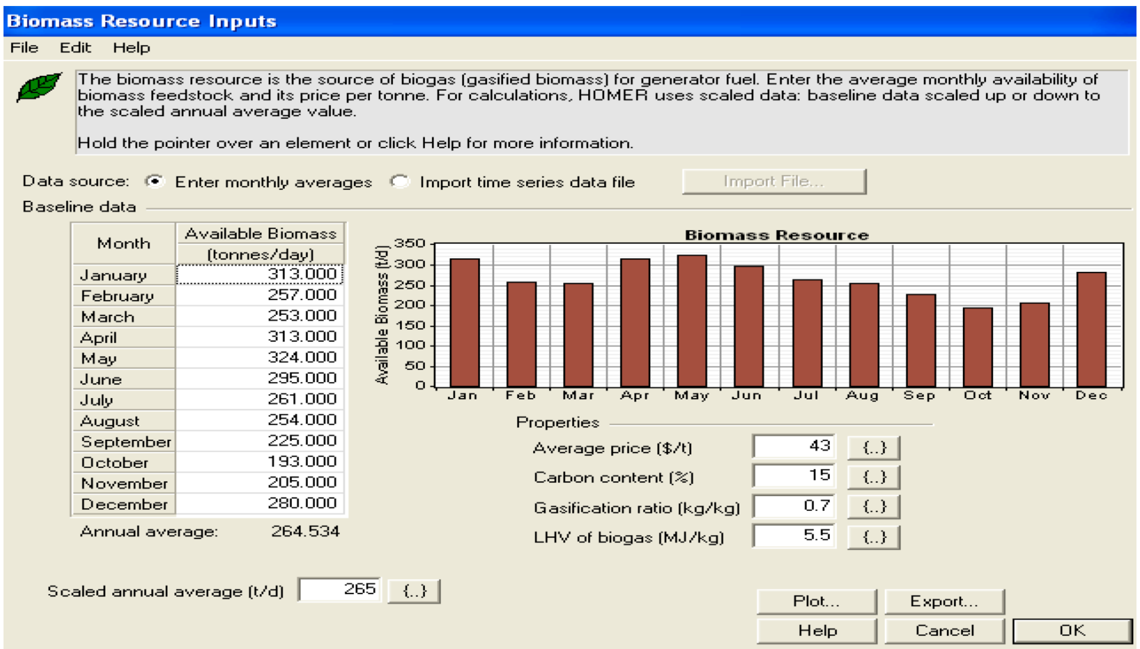
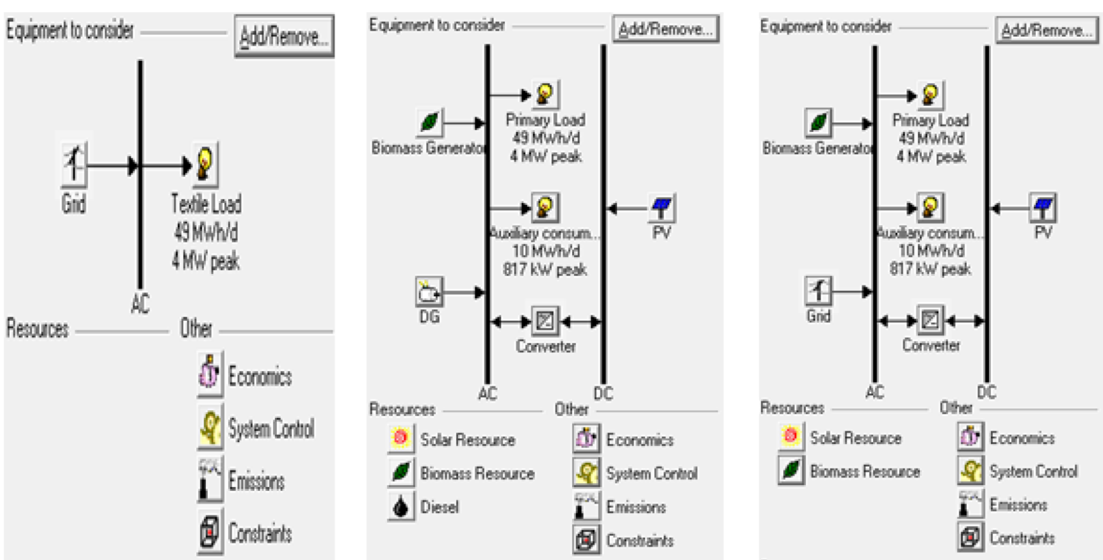


Figure 3. Average monthly biomass feedstock availability.



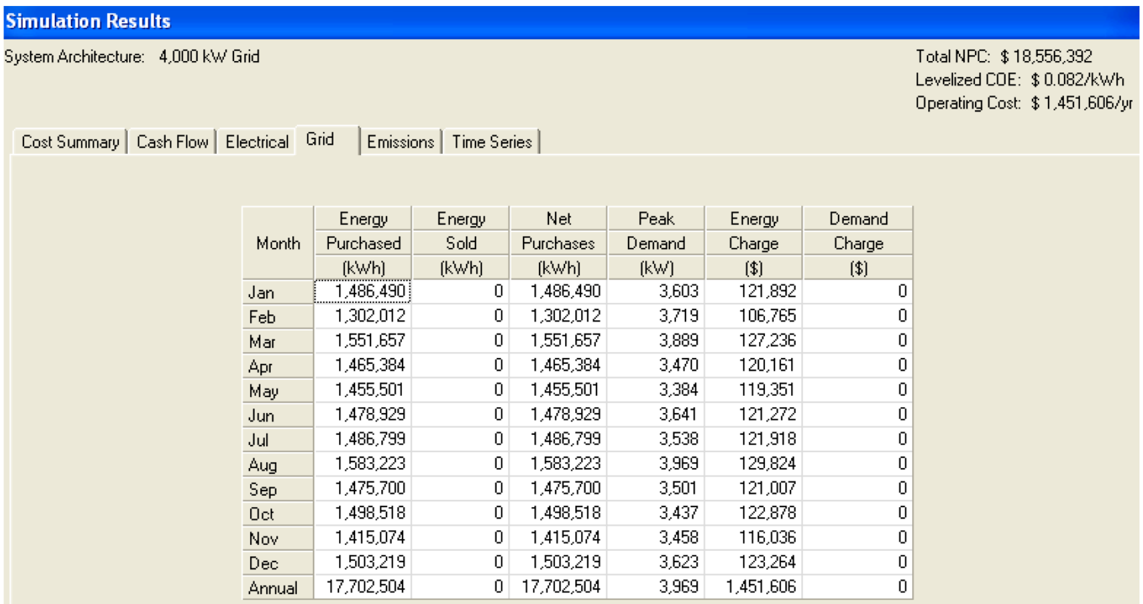
Scenario-1 Scenario-2 Scenario-3

Figure 4. Schematic diagram of the scenarios analyzed.

CO_2 emissions are very high at about 15,047,128 kg/year for the grid-only system, as seen in Table 6. The average monthly energy purchases from the grid for the given load profile are depicted in Figure 5.

Table 6. Cost and emission analysis.

Parameters	Economic parameters and CO_2 emissions		
	Scenario 1	Scenario 2	Scenario 3
NPC ($)	18,556,392	37,415,384	35,843,284
LCOE ($/kWh)	0.082	0.137	0.131
Operating cost ($/year)	1,451,606	2,550,729	2,459,705
CO_2 emissions (kg/year)	15,047,128	103,434	5,465,770


Simulation Results

System Architecture: 4,000 kW Grid

Total NPC: $ 18,556,392
Levelized COE: $ 0.082/kWh
Operating Cost: $ 1,451,606/yr

Cost Summary | Cash Flow | Electrical | Grid | Emissions | Time Series

Month	Energy Purchased (kWh)	Energy Sold (kWh)	Net Purchases (kWh)	Peak Demand (kW)	Energy Charge ($)	Demand Charge ($)
Jan	1,486,490	0	1,486,490	3,603	121,892	0
Feb	1,302,012	0	1,302,012	3,719	106,765	0
Mar	1,551,657	0	1,551,657	3,889	127,236	0
Apr	1,465,384	0	1,465,384	3,470	120,161	0
May	1,455,501	0	1,455,501	3,384	119,351	0
Jun	1,478,929	0	1,478,929	3,641	121,272	0
Jul	1,486,799	0	1,486,799	3,538	121,918	0
Aug	1,583,223	0	1,583,223	3,969	129,824	0
Sep	1,475,700	0	1,475,700	3,501	121,007	0
Oct	1,498,518	0	1,498,518	3,437	122,878	0
Nov	1,415,074	0	1,415,074	3,458	116,036	0
Dec	1,503,219	0	1,503,219	3,623	123,264	0
Annual	17,702,504	0	17,702,504	3,969	1,451,606	0

Figure 5. Average monthly energy purchases from the grid.

2.5.2. Scenario 2: standalone biomass-solar hybrid system

As 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, the feasibility of the hybrid system is analyzed for meeting the demands of the textile mill. A 4 MW biomass power system has been modeled to supply the textile load and a diesel generator is utilized to meet the auxiliary power consumption of the boiler-turbine generator set. The biomass feedstock consumption and price per ton are given as resource inputs in HOMER. The approximate lighting load of the yarn mill is around 100 kW and hence the rating of the PV system is chosen as 100 kW. The aim of this scenario is to meet the utilization of electricity of the industrial processing plant with a biomass-solar hybrid system. Since the region is agriculture-prone area, feedstock is assumed to be available throughout the year. The system produces 21,204,572 kWh $year^{-1}$ (99%) of the total electricity required with biomass fuel consumption of 56,666 t/year and 143,681 kWh $year^{-1}$ (1%) of the total electricity with solar energy, resulting in a NPC of $37,415,384. From Table 6, it is seen that the levelized cost of energy (LCOE) is $0.137/kWh. The CO_2 emissions are lowest in this case at about 103,434 kg/year and can be lowered to 30,834 kg/year if a diesel generator is not used.

2.5.3. Scenario 3: grid-connected biomass-solar hybrid system

The electrical energy production from the grid-connected solar and biomass generator is presented in Figure 6. The cost and emission results of the scenarios are shown in Table 6. It can be observed that the NPC of the grid-connected hybrid system is $35,843,284 and it is higher than that of the grid-only system due to the high feedstock rate of the biomass system and the investment cost involved in the PV-biomass system. The CO_2 emissions are higher in this case at about 5,465,770 kg/year because the conventional grid is used to meet the auxiliary consumption of the biomass system. With advancement in technology, the price can be reduced and renewables will become the trend of the future.

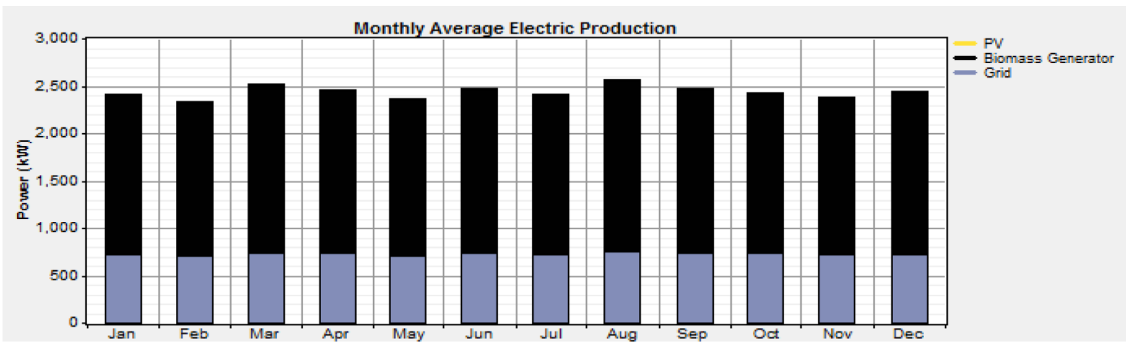


Figure 6. Electrical energy production from the grid-connected hybrid system.

3. Optimization of biomass feedstock using neural network

The average price of biomass fuel is around $38.5–$42 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, the optimal amount of fuel is to be used to reduce the costs incurred and to get maximum power output from the plant.

Using the data provided by AMBEML as depicted in Table 7, optimization of the feedstock consumption is performed 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, data consisting of 6 input vectors for the biomass fuel types and one target vector for the gross electricity generation are loaded as shown in Table 7. A feedforward network is created [12] with a default tan-sigmoid transfer function in the hidden layer and linear transfer function in the output layer. Twenty neurons are used in one hidden layer. The network has one output neuron, because only one target value is associated with the input vectors. The network uses the default Levenberg–Marquardt algorithm for training as shown in Figure 7. 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 overfitting, and the last 20% are used as a completely independent test of network generalization. The performance plot is shown in Figure 8.

The network is trained with 18 data of biomass fuel consumed and the optimized results for the 4 MW power generation are obtained as displayed in Figure 9. The optimized value of the 6 fuel types is found to be a total of 6951 t, which has been utilized for the economic evaluation of the hybrid system dealt with in the next section. The optimized value of the fuels obtained from the result is found to be very close to the quantity used by the plant operator as suggested by the management of AMBEML.

Table 7. Consumption of biomass fuel types by AMBEML.

Month, year	Types of biomass fuel consumed (t)						Gross electricity generated (kWh)
	Juliflora	Bagasse	Paddy husk	Ply wood waste	Ground nut shell	Coconut fiber	
Apr 2011	4856.16	1401.79	2255.35	96.899	347.791	486.676	5,889,700
May 2011	5388.91	625.455	2089.57	214.996	76.959	493.893	5,870,800
Jun 2011	4846.07	455.69	3257.12	472.925	16.474	916.573	6,582,800
Jul 2011	385.48	136.88	383.24	122.91	0.82	88.735	676,400
Aug 2011	1236.83	767.07	828.298	13.625	0	367.425	2,143,900
Sep 2011	3459.27	1048.14	2509.35	350.54	15.885	1352.25	5,422,500
Oct 2011	3114.41	369.535	1640.65	141.54	26.49	1553.58	3,603,800
Nov 2011	2500.72	87.05	2288.29	75.723	29.07	1145.77	2,699,100
Dec 2011	4428.89	271.99	1736.54	32.51	12.3	1347.25	3,875,000
Jan 2012	4067.79	1248.06	1894.83	86.28	10.04	2397.78	5,285,900
Feb 2012	2771.16	1401.1	643.225	78.075	14.69	2291.935	3,889,700
Mar 2012	3762.2	1458.99	750.645	58.635	87.4	1751.105	4,297,700
Apr 2012	5913.348	986.786	1057.078	114.708	126.489	1191.648	6,190,300
May 2012	5213.36	2012.65	907.583	90.468	34.396	1785.86	5,986,300
June 2012	5068.374	1099.289	905.675	137.09	64.176	1587.596	5,207,400
Jul 2012	3629.891	939.943	1907.771	28.03	81.322	1515.095	4,962,700
Aug 2012	4230.476	665.067	1627.75	110.378	67.34	1177.803	5,296,500
Sep 2012	3511.732	643.555	1325.523	167.855	39.425	1083.694	4,306,100
Oct 2012	3979.993	80.55	640.53	188.45	0	1153.393	4,139,100

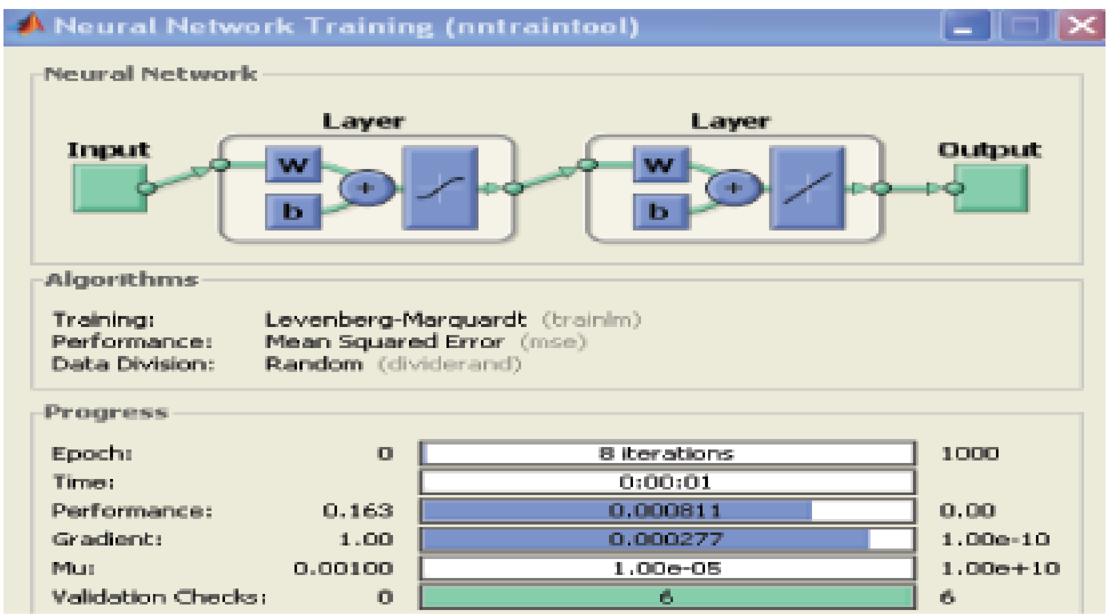


Figure 7. Neural network used for optimization.

3.1. Economic evaluation of solar-biomass hybrid system

As there is enough potential of solar energy and biomass in the T.Kallupatti region, the economic feasibility of the hybrid system is as follows: 4 MW biomass generation system and 100 kW PV system are considered here.

Table 8 enumerates the cost of 100 kW solar PV-battery systems including the subsidy of 30% for solar panels from the Ministry for New and Renewable Energy.

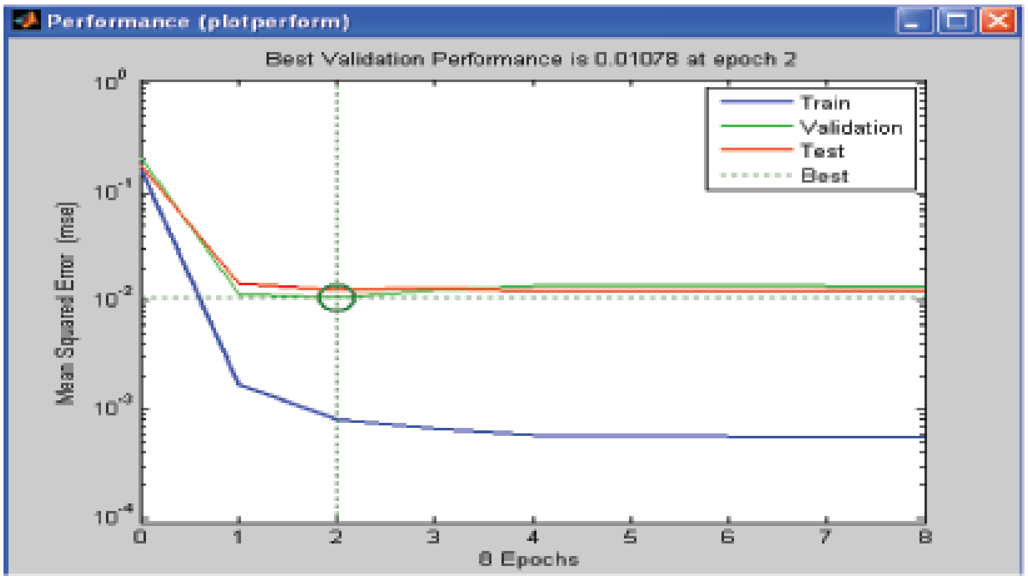


Figure 8. Performance plot of ANN optimization.

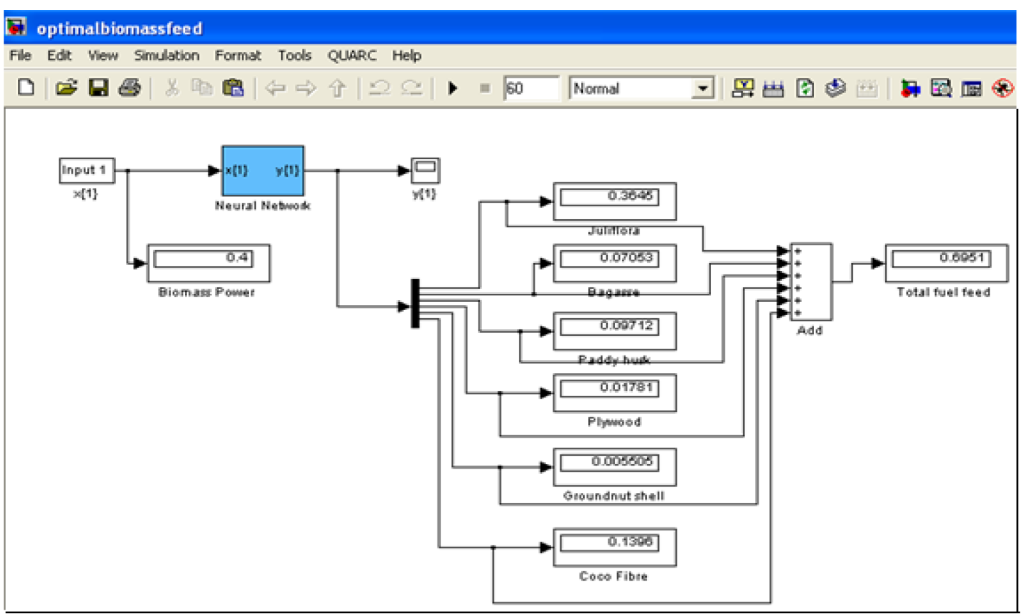


Figure 9. Optimal fuel feed combination using ANN.

Table 8. Overall cost of 100 kW solar PV system with battery.

Power plant details	400 panels of 250 Wp, cost in $	400 kVA inverter cost (includes power conditioning unit) in $	Battery bank (400 nos., 150 Ah tubular) cost in $	Connecting cable cost in $	Mounting structure cost including erection cost in $	Total cost of system in $
100 kW	76,923	18,462	80,000	4769	25,385	205,539

Solar PV system:

Installation cost of 100 kW PV system = \$205,539 (from Table 8)

Maintenance cost of the PV plant = 1% of the installation cost = \$2055

Total cost of the PV system= \$207,593.50

Operating years = 20 years

No. of sunshine hours = 7 (0900 to 1600 hours)

Assuming that PV arrays generate at 70% of rated capacity:

Per day generation of the PV system = $100 \times 7 \times 0.7 = 490$ units

Per unit cost = 207,593.5 / ($20 \times 365 \times 490$) = \$0.058

Biomass power system:

Installation cost of 4 MW biomass plant = \$3,692,308

Maintenance cost of the biomass plant = 2% of the installation cost = \$73,846

Biomass fuel feedstock required for 4 MW plant = 6951 t/month

Average cost of biomass feedstock fuel for the chosen region = \$42/t

Purchase cost of feedstock = \$3,503,304

Total cost of the plant including fuel purchase cost = \$7,269,458

Operating years = 20 years

Per day generation = 49,000 units

Per unit cost = 7,269,458 / ($20 \times 49{,}000 \times 365$) = \$0.0203

Hybrid system:

Per unit cost of hybrid system = (0.058 + 0.0203) / 2 = \$0.04

Through the hybrid energy system, per unit cost of generation is \$0.04. However, through the conventional grid connection, per unit tariff for industries is a minimum of \$0.085. Therefore, the generation cost of the hybrid renewable energy system is comparatively less than that of the conventional grid system and the hybrid system is appropriate for industries with potential resource availability.

3.2. Computation of carbon credit

The CO_2 emissions of the three scenarios analyzed in Section 2.4 are given in Figure 10. This justifies that the standalone biomass-solar hybrid system is a sustainable energy option for the textile industry. The certified emission reductions (CERs) for the standalone biomass-solar hybrid system are computed in Table 9. If the plant is a Clean Development Mechanism registered project activity, it can be seen from the table that the total earnings from the carbon saved is about 0.30 million dollars.

4. Conclusion

In this work, the feasibility of a PV/biomass hybrid system for a textile industry is analyzed based on the resource availability in an existing biomass project activity at Kadaneri near the industrial locality. The economic viability of the proposed hybrid system is evaluated using HOMER to determine the sustainable energy options for the industry in the T.Kallupatti region. The economics of solar-biomass hybrid power generation are presented with an example calculation. The following conclusions are drawn based on the results of the analysis:

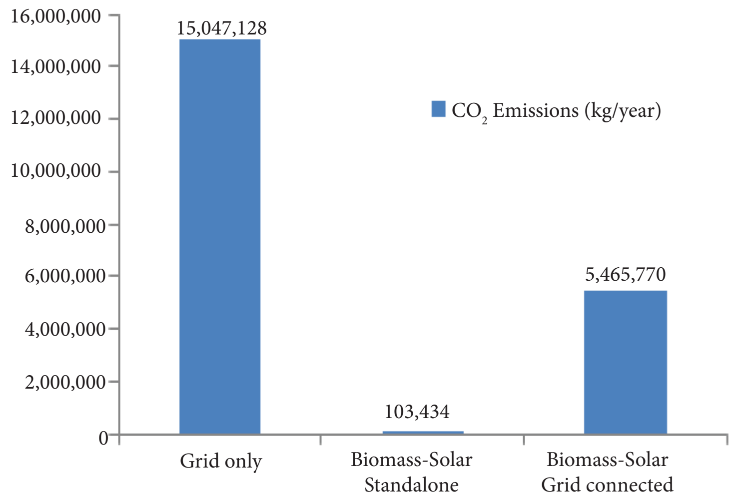


Figure 10. CO_2 emissions of the three scenarios analyzed.

Table 9. Computation of carbon credit.

Carbon saved per kWh by biomass power	0.85 kg
Estimated net generation	21,205 MWh from biomass + 143,68 kWh from solar
Carbon saved by biomass power	18,024 t
Carbon saved per kWh by solar generation	0.106 kg
Carbon saved by solar power	15 t
Total CERs for hybrid system	18,039
Market price per tons in dollars	16.8
Total earnings in dollars	0.30 million

- Biomass is the promising key of the future for industries in agriculture-prone areas in India and the generation cost is less compared to the conventional energy system.
- CO_2 emissions are much lower with a standalone biomass-based RE system compared to that of the grid-based system.
- From the economic point of view, biomass-based electricity generation is cheaper compared to other generation options in the aspect of converting existing coal-fired cogeneration plants into biomass plants and high capital investment is required for new solar and wind installations.

The economic analysis shows that the grid-only system costs less than the hybrid biomass-solar system in the present scenario. In the future, with successful technological upgrades, the price of the PV-biomass system can be lowered and it will become the best renewable and sustainable energy option in India. With increasing diesel prices and specific power requirements year by year, and uncertain grid power availability, the proposed hybrid biomass-solar power system will become the inevitable generation option for textile factories located in regions where surplus biomass-solar resources exist.

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References

[1] Singh R, Setiawan AD. Biomass energy policies and strategies: harvesting potential in India and Indonesia. Renew Sust Energ Rev 2013; 22: 332–345.

[2] Khare V, Nema S, Baredar P. Status of solar wind renewable energy in India. Renew Sust Energ Rev 2013; 27: 1–10.

[3] Ravindranath NH, Balachandra P, Dasappa S, Usha Rao K. Bioenergy technologies for carbon abatement . Biomass Bioenerg 2006; 30: 826–837.

[4] Bekele G, Tadesse G. Feasibility study of small Hydro/PV/Wind hybrid system for off-grid rural electrification in Ethiopia. Appl Energ 2012; 97: 5–15.

[5] Razak JA, Sopian K, Ali Y, Alghoul MA, Zaharim A, Ahmad I. Optimization of PV–wind–hydro–diesel hybrid system by minimizing excess capacity. EJSR 2009; 25: 663–671.

[6] Ashourian MH, Cherati SM, Zin AAM, Niknam N, Mokhtar AS, Anwari M. Optimal green energy management for island resorts in Malaysia. Renew Energ 2013; 51: 36–45.

[7] Aagreh Y, Al-Ghzawi A. Feasibility of utilizing renewable energy systems for a small hotel in Ajloun city, Jordan. Appl Energ 2013; 103: 25–31.

[8] Hafez O, Bhattacharya K. Optimal planning and design of a renewable energy based supply system for microgrids. Renew Energ 2012; 45: 7–15.

[9] Türkay BE, Telli AY. Economic analysis of standalone and grid connected hybrid energy systems. Renew Energ 2011; 36: 1931–1943.

[10] Nouni MR, Mullick SC, Kandpal TC. Biomass gasifier projects for decentralized power supply in India: a financial evaluation. Energ Policy 2007; 35: 1373–1385.

[11] Kishore VVN, Bhandari PM, Gupta P. Biomass energy technologies for rural infrastructure and village power-opportunities and challenges in the context of global climate change concerns. Energ Policy 2004; 32: 801–810.

[12] Alam S, Kaushik SC, Garg SN. Assessment of diffuse solar energy under general sky condition using artificial neural network. Appl Energ 2009; 86: 554–564.